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2-21-02

Applicant	Robert T. Gallagher	TRANSMITTAL FORM UNDER 37 C.F.R. §1.8 (Large Entity)
Serial No.	09/273,197	
Filing Date	March 19, 1999	
Group Art Unit	2731	
Examiner Name	Unknown	
Attorney Docket No.	100.044US01	
Title: DIGITAL RETURN PATH FOR HYBRID FIBER/COAX NETWORK		

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Washington, DC 20231

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Enclosures

The following documents are enclosed:

X A Fourth Supplemental Information Disclosure Statement (1 pg.);
X Form 1449 (1 pg.);
X Copies of 11 documents;
X Communication Re: Co-pending and/or Related Applications; Copies of Specifications and Drawings of Co-pending and/or Related Applications; and
X A return postcard.

Please charge any additional fees or credit any overpayments to Deposit Account No. 501373.

Submitted By

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Certificate of Mailing

I certify that this correspondence, and the documents identified above, are being deposited with the United States Postal Service as first class mail in an envelope addressed to: Commissioner for Patents, Washington, D.C. 20231 on January 30, 2002.

Name	Kristen Smith	Signature	Kristen Smith

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Applicant	Robert T. Gallagher	FOURTH SUPPLEMENTAL INFORMATION DISCLOSURE STATEMENT
Serial No.	09/273,197	
Filing Date	March 19, 1999	
Group Art Unit	2731	
Examiner	Unknown	
Attorney Docket No.	100.044US01	
Title: DIGITAL RETURN PATH FOR HYBRID FIBER/COAX NETWORK		

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Commissioner for Patents
Washington, D.C. 20231

In compliance with 37 C.F.R. §§ 1.56 and 1.97, *et seq.*, the enclosed materials are brought to the attention of the Examiner for consideration in connection with the above-identified Application. Applicant respectfully requests that this Second Supplemental Information Disclosure Statement be entered and the references listed on the attached Form 1449 be considered by the Examiner and made of record. Pursuant to MPEP §609, Applicant further requests that the Examiner initial next to each reference on the Form 1449 to indicate that the listed references have been considered. Applicant further requests that a copy of the initialed Form 1449 be returned with the next official communication.

Under 37 C.F.R. § 1.97(b)(3), it is believed that no fee or certificate is required with this Information Disclosure Statement. However, if an Office Action on the merits has been mailed, the Commissioner is hereby authorized to charge any fees deemed necessary or credit any overpayment to Deposit Account No. 501373.

The Examiner is invited to contact the Applicant's Representative at the below-listed telephone number if there are any questions regarding this communication.

Respectfully submitted,

Date: Jan 30, 2002

David N. Fogg
Reg. No. 35,138

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First Named Inventor	Robert T. Gallagher	COMMUNICATION RE: CO-PENDING AND/OR RELATED APPLICATIONS
Serial No.	09/273,197	
Filing Date	March 19, 1999	
Group Art Unit	2731	
Examiner Name	Unknown	
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Washington, D.C. 20231

In compliance with 37 C.F.R. §§ 1.56 and 1.97, *et seq.* and MPEP §2001.06(b), Applicant respectfully draws the Examiner's attention to the following co-pending and/or related applications:

Atty. Docket #	U.S. Serial #	Filing Date	Title
100.115US01	09/433,332	11/03/99	DIGITAL RETURN PATH FOR HYBRID/FIBER COAX NETWORK
100.120US01	09/432,558	11/03/99	DIGITAL NODE FOR HYBRID/FIBER COAX NETWORK
100.019US01	09/619,431	07/19/00	POINT-TO-MULTIPOINT DIGITAL RADIO FREQUENCY TRANSPORT

A copy of the specification and drawings of each of the co-pending and/or related applications is enclosed for the Examiner's review. The Commissioner is hereby authorized to charge any fees deemed necessary or credit any overpayment to Account No. 501373.

The Examiner is invited to contact the Applicant's Representative at the below-listed telephone number if they are any questions regarding this communication.

Respectfully submitted,

Date: Jan 30, 2002

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09/433,332

Digital Return Path for Hybrid Fiber/Coax Network

Cross Reference to Related Applications

This application is related to the following commonly assigned, co-pending applications:

U.S. Application Serial No. 09/273,197, entitled "DIGITAL RETURN PATH FOR HYBRID FIBER/COAX NETWORK" and filed on March 19, 1999 (Attorney Docket No. 500.714US1) (the "714 Application"), and

U.S. Application Serial No. _________, filed on the same date as the present application and entitled "DIGITAL NODE FOR HYBRID FIBER/COAX NETWORK" (Attorney Docket No. 500.731US1) (the "731 Application").

The 714 Application and the 731 Application are incorporated by reference.

Technical Field of the Invention

The present invention relates generally to the field of telecommunications and, in particular, to a digital return path for a hybrid fiber/coax network.

Background

Cable networks originally carried programming from a head end to subscribers over a network of coaxial cable. Over time, these networks have changed. Some cable networks now include fiber optic links as part of the network. This variety of cable network is colloquially referred to as a "hybrid fiber/coax" (HFC) network.

A hybrid fiber/coax network typically includes a head end that broadcasts programming over the network to subscribers in a downstream direction. The network includes two main portions. The first portion of the network is optical links that connect the head end with a number of geographically dispersed distribution nodes. These nodes are referred to as "optical distribution nodes" or "ODNs." At the ODNs, signals from the head end that carry the programming are converted from optical signals to electrical signals. The second portion of the network is coaxial links that connect the

ODNs with subscriber equipment. The electrical signals are transmitted to the subscriber equipment over the coaxial cable links.

In recent years, the cable industry has experimented with systems that allow for bi-directional communication between subscriber equipment and the head end. This allows for services such as video-on-demand, telephony and Internet traffic to be offered over a cable network. Typically the 5 to 42 MHZ frequency range is reserved for upstream transmission from customers to the head end. Frequencies between 50 MHZ and an upper limit, e.g., 750 MHZ or 850 MHZ, typically carry downstream transmissions.

The design of the reverse path for transporting data over a hybrid fiber/coax network is laced with difficult technical issues. First, many customers must communicate over a common coaxial cable. Interference between customers and noise ingress onto the cable can cause disruptions and errors in this communication. Ingress and other interference is especially a problem at the low frequencies typically prescribed for upstream communications. Transporting simultaneous data transmissions from many customers also introduces complexity into the system design.

In most current systems, the reverse path is implemented with one of a number of different analog modulation schemes, e.g., MCNS, Data Over Cable Service Interface Specification (DOCSIS). These schemes are complicated to implement due to strict timing requirements and complex modulation schemes. Other systems, such as AT&T's mini fiber node (mFNs), introduce other complexities into the return path.

For the reasons stated above, and for other reasons stated below which will become apparent to those skilled in the art upon reading and understanding the present specification, there is a need in the art for an improved return path for a hybrid fiber/coax network.

Summary

The above mentioned problems with telecommunications systems and other problems are addressed by the present invention and will be understood by reading and studying the following specification. A hybrid fiber/coax network is described which includes an optical distribution node that combines CSMA/CD error detection through frequency translation ("frequency turn-around") with data concentration. In another embodiment, a hybrid fiber/coax network is described which includes a digital return path that transmits upstream, digital data from modems to a head end using modulated carriers that reside, at least in part, below the conventional downstream frequency band, e.g., below 42 MHZ. Problems with contention for bandwidth and ingress noise in this frequency spectrum are addressed through a collision detection mechanism that monitors transmissions on the coaxial cable links of the HFC network.

In one embodiment, an optical distribution node for an hybrid fiber/coax network is provided. The optical distribution node includes a laser transmitter coupleable to a fiber optic link that transmits upstream, digital data to a head end of the network. The node also includes a data concentrator coupled to provide the upstream, digital data to the laser. For at least one coaxial cable link of the network coupleable to the optical distribution node, the node also includes a frequency translator that receives the upstream, digital data modulated on a first carrier frequency and retransmits the upstream, digital data to the plurality of modems for collision detection. The node also includes a data interface coupled between the at least one coaxial cable link and the data concentrator that determines whether the upstream data is valid.

Brief Description of the Drawings

Figure 1 is a block diagram of an embodiment of a hybrid fiber/coax network constructed according to the teachings of the present invention.

Figure 2 is a dataflow diagram that illustrates an embodiment of a layered implementation of communication protocol stacks for an optical distribution node according to the teachings of the present invention.

Detailed Description

The following detailed description refers to the accompanying drawings which form a part of the specification. The drawings show, and the detailed description describes, by way of illustration specific illustrative embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention. Other embodiments may be used and logical, mechanical and electrical changes may be made without departing from the scope of the present invention. The following detailed description is, therefore, not to be taken in a limiting sense.

Figure 1 is a block diagram of an embodiment of a hybrid fiber/coax network, indicated generally at 100, and constructed according to the teachings of the present invention. Network 100 is a bi-directional network that carries signals between head end or hub 102 and a number of modems 103-1-1, . . . , 103-M-N. Advantageously, the return path of network 100 is constructed so as to carry the data in digital format, e.g., as Ethernet or other packets of digital data using Internet Protocol (IP), from modems 103-1-1, . . ., 103-M-N to head end 102, thus providing an all digital return path.

Head end 102 is coupled to modems 103-1-1, . . ., 103-M-N over a combination of fiber optics and coaxial cable. Namely, head end 102 is coupled via fiber optic link 105 with optical distribution node 106. Optical distribution node 106 is also coupled to coaxial cable links or branches 108-1, . . ., 108-M. Modems, represented by modems 103-1-1, . . ., 103-M-N, are selectively coupled to coaxial links 108-1, . . ., 108-M via directional couplers 110.

Network 100 includes downstream and upstream (return) paths each of which is described in turn.

In the downstream path, network 100 combines signals from one or more sources at combiner 112 of head end 102. In one embodiment, combiner 112 receives analog and digital video signals. In another embodiment, combiner 112 also receives other data appropriate for transmission over network 100. Combiner 112 is coupled to optical transmitter 114. Optical transmitter 114 provides optical signals to optical distribution node 106 over fiber optic link 115. These optical signals are received by

optical receiver 116 and coupled to coaxial cable links 108-1, . . ., 108-M through diplexers 118-1, . . ., 118-M, respectively.

The downstream data path can use any appropriate data communication protocol, including but not limited to, MCNS and DOCSIS.

In one embodiment, data on fiber optic links 105 and 115 is carried as base-band digital data using on-off keying. In another embodiment, data on fiber optic links 105 and 115 is carried using modulated carriers. Further, data on fiber optic links 105 and 115 is transmitted using the 100BaseT Ethernet protocol or any other standard or custom protocol.

Advantageously, the return path of network 100 carries digital data from modems 103-1-1, . . ., 103-M-N to head end 102. In one embodiment, modems 103-1-1, . . ., 103-M-N transmit Ethernet packets over network 100. In this embodiment, modems 103-1-1, . . ., 103-M-N include standard Ethernet interfaces 120-1-1, . . ., 120-M-N, respectively. It is understood that in other embodiments, an appropriate interface is used based on the format of the data being transmitted over network 100. Interfaces 120-1-1, . . ., 120-M-N are coupled to media access units 122-1-1, . . ., 122-M-N, respectively. Media access units 122-1-1, . . ., 122-M-N provide physical layer interface for modems 103-1-1, . . ., 103-M-N, respectively.

Optical distribution node 106 includes upstream path circuitry for each coaxial cable link 108-1, . . ., 108-M. Due to the similarity between the circuitry for each coaxial cable link, only the upstream path in optical distribution node 106 for coaxial cable link 108-1 is described here. However, it is understood that the remaining coaxial cable links include similar circuitry in optical distribution node 106.

In one embodiment, modems 103-1-1, . . ., 103-1-N launch digital data on coaxial cable link 108-1 by on-off-keying of one of a selected number of radio frequency carriers, designated f_1 or f_3 in Figure 1 with digital data in the form of Ethernet packets. In other embodiments other modulation techniques are used, e.g., quadrature phase shift keying (QPSK), quadrature amplitude modulation (QAM), and other appropriate modulation techniques. Each modem 103-1-1, . . ., 103-1-N uses one of the select number of carriers. It is understood that any appropriate number of carriers

can be used. In one embodiment, each of the select number of carriers falls in the frequency range below the downstream frequency range, e.g., below 42 MHZ. In other embodiments, one or more of the select number of carriers has a frequency above the downstream frequency range, e.g., above 750 MHZ or 850 MHZ. In another embodiment, one or more of the selected carriers falls within the frequency range which is conventionally reserved for downstream transmissions from the head end. In another embodiment, one or more of the carriers is located on other frequencies that are conventionally used for downstream transmission, e.g., a carrier in the frequency range from 50 to 860 MHZ.

The upstream path of optical distribution node 106 includes frequency translator 124 that is coupled to coaxial cable link 108-1 through couplers 126 and 128. The output of frequency translator 124 is coupled to coupler 126.

Frequency translator 124 provides a loopback mechanism to implement a collision detection protocol for the upstream path of network 100 on coaxial cable link 108-1. Frequency translator 124 translates modulated carriers, e.g., f_1 and f_3, to other frequencies, e.g., f_2 and f_4, respectively. Essentially, frequency translator 124 provides aggregate data received from all modems 103-1-1, . . ., 103-1-N on coaxial cable link 108-1 back to modems 103-1-1, . . ., 103-1-N. Each modem 103-1-1, . . ., 103-1-N compares its transmitted data with the aggregate data to determine whether its data was received at optical distribution node 106 without collision with other data or without corruption from ingress noise.

When a modem detects a collision, the modem provides a collision detection signal on another carrier. The modem further waits a randomly selected period of time to attempt retransmission. Advantageously, this process allows network 100 to transmit digital, upstream signals in the conventional upstream band despite ingress and other interference since interference looks like a collision to network 100 and data affected by the interference is automatically retransmitted.

Optical distribution node 106 also includes coupler 130 that provides data to media access units 132 and 134. Each media access unit 132 and 134 is provided to handle data for each modulated carrier used by modems 103-1-1, . . ., 103-M-N on

coaxial cable link 108-1. Media access units 132 and 134 are coupled to data concentrator 136 through interface circuits 138 and 140, respectively. Interface circuits 138 and 140 determine whether the data received from coaxial cable link 108-1 is valid data, e.g., interface circuits 138 and 140 determine whether a collision was detected on coaxial cable link 108-1. Data concentrator 136 concentrates data from coaxial cable links 108-1, . . ., 108-M for transmission upstream to head end 102 by laser 142. In one embodiment, laser 142 transmits the upstream, digital data with base-band on-off-keying using 100BASET data format. At head end 102, the data is switched or routed into a data network, e.g., a standard-based or proprietary, private or public network.

In operation, digital data is transmitted from modems 103-1-1, . . ., 103-M-N over network 100 to head end 102. For example, digital data originating at modem 103-1-1 is provided to coaxial cable 108-1 on a modulated carrier. Frequency translator 124 translates the frequency of the modulated carrier and retransmits the data back to modem 103-1-1 with aggregate data from all modems on coaxial link 108-1. Modem 103-1-1 checks for collisions and if any, transmits a collision detect signal on a separate carrier and then waits a random amount of time and retransmits the data.

In the absence of a collision, the data is passed to data concentrator 136 and concentrated with data from other coaxial links. This data is passed to head end 102 over optical fiber link 105 by transmitter 142. At head end 102, the data is routed or switched to other networks.

Node 106 of Figure 1 advantageously combines CSMA/CD error detection through frequency translation ("frequency turn-around") and data concentration. This combination of functionality is shown in Figure 3. Frequency turn-around is performed at the physical layer as indicated next to blocks 302 and 304. Further, routing functionality, e.g., concentration and switching, is provided at the network layer as indicated by blocks 306 and 308. In this manner, the frequency turn-around scheme does not require modulation or demodulation processes and is kept transparent to the hardware at node 106.

Conclusion

A hybrid fiber/coax network has been described with a digital return path. Essentially, digital data is modulated on one or more carriers within the conventional upstream bandwidth by modems and provided to an optical distribution node. A collision detection process is used by looping back aggregate data to the modems on a common coaxial cable link. The data from a number of coaxial cable links are concentrated and transmitted as digital data over a fiber optic connection to a head end or hub.

Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement which is calculated to achieve the same purpose may be substituted for the specific embodiment shown. This application is intended to cover any adaptations or variations of the present invention. For example, data can be transmitted in formats other than standard Ethernet formats. Further, any appropriate number of carrier frequencies can be used to carry digital data to the optical distribution nodes. Also, a part of the upstream data can be transmitted on carriers that are located above 850 MHZ in the frequency spectrum. This allows the upstream data path to carry more data than the conventional upstream band. Further, it is understood that a portion of the upstream path can be carried on the conventional downstream frequencies, e.g., between 42 and 850 MHZ, if the spectrum is not allocated for downstream communication. An optical distribution node can also support as few as one coaxial cable link. Further, modulation formats other than on-off keying can be used, including, but not limited to quadrature phase-shift keying (QPSK) and quadrature amplitude modulation (QAM). In one embodiment, frequency turn-around at node 106 is accomplished according to ANSI/IEEE standard 802.3 (1996) (the "10BROAD36 standard"). Further, it is understood that a frequency translator can be coupled to one or more coaxial cable links.

What is claimed is:

1. A hybrid fiber/coax network, comprising:

a head end;

at least one optical distribution node coupled to the head end over at least one fiber optic link;

at least one coaxial cable link, coupled to the at least one optical distribution node, that receives upstream, digital data from a plurality of modems; and

wherein the at least one optical distribution node has a digital return path that includes:

a laser transmitter coupled to the fiber optic link that transmits the upstream, digital data to the head end;

a data concentrator coupled to provide the upstream, digital data to the laser; and

for the at least one coaxial cable link,

a frequency translator that receives and translates the upstream, digital data from the plurality of modems to a different carrier frequency and retransmits the signal to the plurality of modems for collision detection; and

a data interface coupled between frequency translator and the data concentrator that determines whether the upstream, digital data is valid.

2. The network of claim 1, wherein at least a portion of the upstream, digital data is transmitted over the at least one coaxial cable link on modulated carriers below 42 MHZ.

3. The network of claim 1, wherein the modulated carriers are modulated with the upstream, digital data using one of on-off-keying, quadrature phase-shift keying and quadrature amplitude modulation.

4. The network of claim 1, wherein the upstream, digital data is carried on one of at least two modulated carriers.

5. The network of claim 1, wherein the plurality of modems transmit collision detection signals on a different modulated carrier when a collision is detected based on signals from the frequency translator.

6. The network of claim 1, wherein the upstream, digital data comprises Ethernet packets.

7. The network of claim 2, wherein at least another portion of the upstream, digital data is transmitted over the plurality of coaxial cable links on modulated carriers above a cut-off frequency for downstream transmissions.

8. The network of claim 1, wherein the laser transmitter transmits the upstream, digital data as one of base-band and modulated carrier transmission.

9. The network of claim 1, and further including a receiver circuit coupled to the fiber optic link and the at least one coaxial cable link that receives downstream optical signals and converts the signals to electrical signals for transmission over the at least one coaxial cable link.

10. A hybrid fiber-coax network, comprising:

a head end;

at least one optical distribution node coupled to the head end over at least one fiber optic link;

at least one coaxial cable link, coupled to the at least one optical distribution node, that receives upstream, digital data from a plurality of modems;

wherein at least a portion of the upstream, digital data is transmitted over the at least one coaxial cable link on at least one modulated carrier below a frequency range for downstream transmission; and

wherein the at least one optical distribution node includes circuitry for detecting collisions on the at least one coaxial cable link.

11. The network of claim 10, wherein the modulated carriers are modulated with the upstream, digital data using one of on-off-keying, quadrature phase-shift keying and quadrature amplitude modulation.

12. The network of claim 10, wherein the upstream, digital data is carried on one of at least two modulated carriers.

13. The network of claim 10, wherein the plurality of modems transmit collision detection signals on a different modulated carrier when a collision is detected based on signals from the frequency translator.

14. The network of claim 10, wherein the upstream, digital data comprises Ethernet packets.

15. The network of claim 10, wherein at least another portion of the upstream, digital data is transmitted over the at least one coaxial cable link on modulated carriers above a cut-off frequency for the downstream transmissions.

16. The network of claim 10, wherein the at least one optical distribution node transmits the upstream, digital data as one of base-band and modulated carrier transmission.

17. The network of claim 10, and further including a receiver circuit coupled to the fiber optic link and the at least one coaxial cable link that receives downstream optical

signals and converts the signals to electrical signals for transmission over the at least one coaxial cable link.

18. An optical distribution node for an hybrid fiber/coax network, the optical distribution node comprising:

a laser transmitter coupleable to a fiber optic link that transmits upstream, digital data to a head end of the network;

a data concentrator coupled to provide the upstream, digital data to the laser; and

for at least one coaxial cable link of the network coupleable to the optical distribution node,

a frequency translator that receives the upstream, digital data modulated on a first carrier frequency from a plurality of modems and translates the upstream, digital data to a different carrier and retransmits the upstream, digital data to the plurality of modems for collision detection; and

a data interface coupled between the at least one coaxial cable link and the data concentrator that determines whether the upstream data is valid.

19. The node of claim 18, and further including at least one media access unit coupled to the at least one coaxial cable link and the data concentrator.

20. The node of claim 18, wherein the upstream, digital data comprises Ethernet packets.

21. The node of claim 18, wherein the laser transmitter transmits the upstream, digital data as one of base-band and modulated carrier transmission.

22. The node of claim 18, wherein the frequency translator also receives upstream, digital data on at least one additional carrier.

23. The node of claim 18, wherein the frequency translator receives the upstream, digital data modulated on a first carrier with a frequency that is below the frequency range for downstream transmissions.

24. A method for processing data in a return path of a hybrid fiber/coax network, the method comprising:

receiving, on a first coaxial cable, upstream, digital data modulated on a first carrier;

translating the frequency of the first carrier to a second frequency;

retransmitting the upstream, digital data modulated on the carrier with the second frequency;

checking for collision detection signals based on the retransmitted upstream, digital data;

concentrating the upstream, digital data with upstream, digital data from other coaxial cables; and

transmitting the concentrated, upstream, digital data to the head end.

25. The method of claim 24, wherein receiving digital data comprises receiving digital data on a first carrier below a frequency range for downstream transmission.

26. The method of claim 24, wherein translating the frequency of the first carrier comprises translating the frequency of the first carrier to a second frequency below the frequency used for downstream transmission.

27. The method of claim 24, wherein checking for collision detection signals comprises monitoring a third frequency for collision detection signals.

28. The method of claim 24, wherein transmitting the concentrated, upstream, digital data comprises transmitting base-band signals as one of base-band and modulated carrier transmission.

29. The method of claim 24, wherein receiving, on a coaxial cable, upstream, digital data comprises receiving Ethernet packets on a modulated carrier.

Abstract of the Disclosure

An optical distribution node for an hybrid fiber/coax network is provided. The optical distribution node includes a laser transmitter coupleable to a fiber optic link that transmits upstream, digital data to a head end of the network. The node also includes a data concentrator coupled to provide the upstream, digital data to the laser. For at least one coaxial cable link of the network coupleable to the optical distribution node, the node also includes a frequency translator that receives the upstream, digital data modulated on a first carrier frequency and retransmits the upstream, digital data to the plurality of modems for collision detection. The node also includes a data interface coupled between the at least one coaxial cable link and the data concentrator that determines whether the upstream data is valid.

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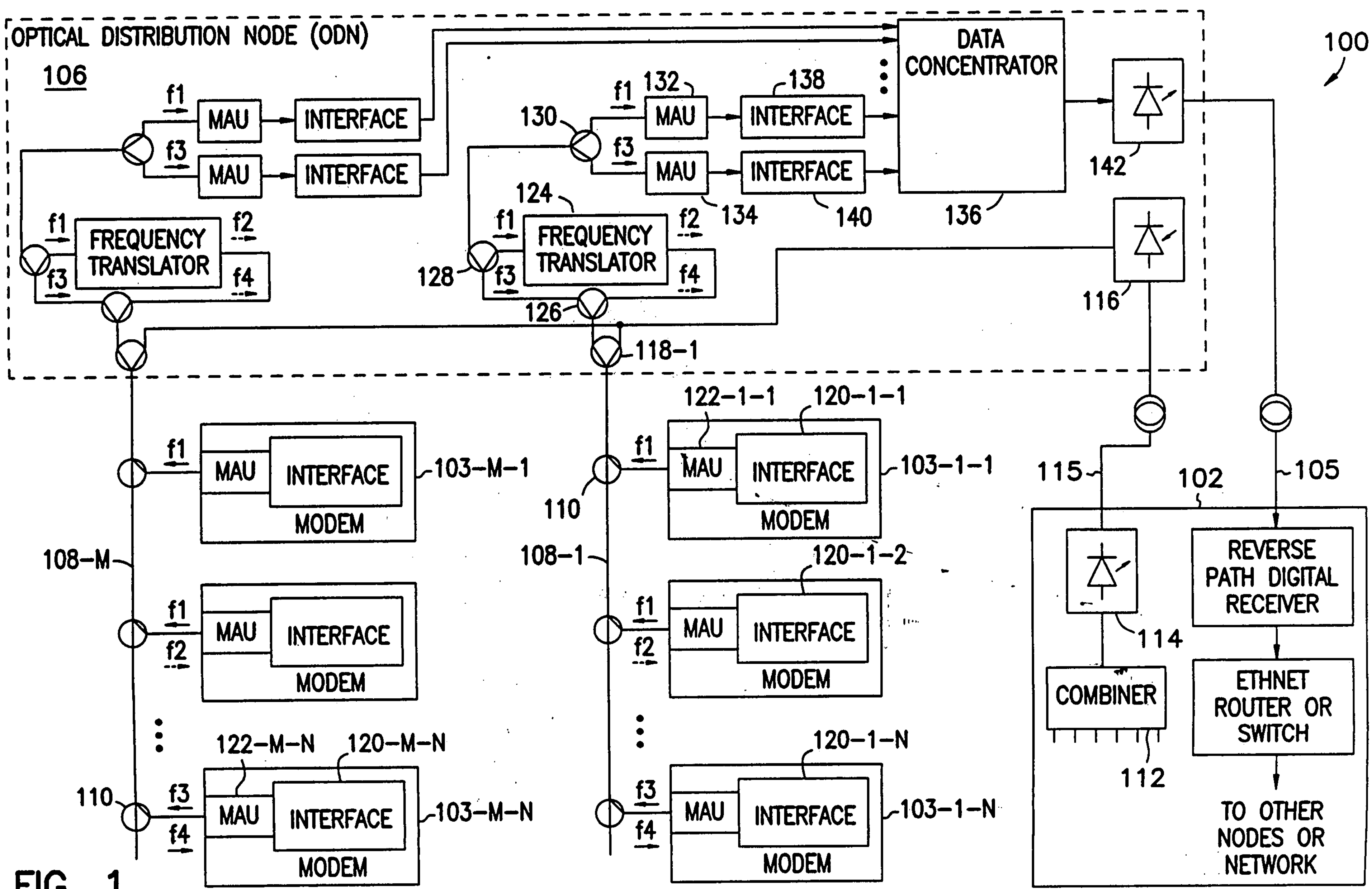
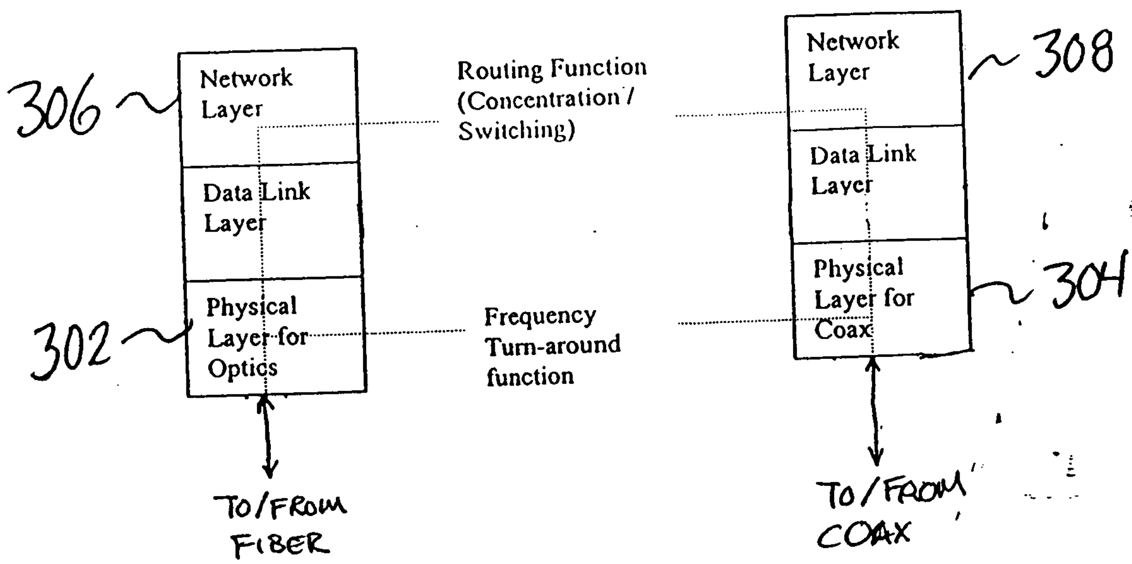
Printed Name: CHRIS HAMMOND
Signature: Chris Hammond



OPTICAL DISTRIBUTION NODE (ODN)
106
100
f1
f3
MAU
MAU
INTERFACE
INTERFACE
FREQUENCY TRANSLATOR
f2
f4
130
132
138
124
128
126
134
140
136
DATA CONCENTRATOR
142
116
118-1
122-1-1
120-1-1
103-1-1
110
108-1
120-1-2
120-1-N
103-1-N
103-M-1
108-M
122-M-N
120-M-N
103-M-N
MODEM
115
102
105
REVERSE PATH DIGITAL RECEIVER
114
COMBINER
112
ETHNET ROUTER OR SWITCH
TO OTHER NODES OR NETWORK

FIG. 1



Network Layer
Data Link Layer
Physical Layer for Optics
306
302
TO/FROM FIBER
Routing Function (Concentration / Switching)
Frequency Turn-around function
Network Layer
Data Link Layer
Physical Layer for Coax
308
304
TO/FROM COAX

FIG. 2

09/432,558

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Digital Node for Hybrid Fiber/Coax Network

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Cross Reference to Related Applications

This application is related to the following commonly assigned, co-pending applications:

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U.S. Application Serial No. _________, filed on the same date as the present application and entitled "DIGITAL RETURN PATH FOR HYBRID FIBER/COAX NETWORK" (Attorney Docket No. 500.722US1) (the "722 Application").

The 714 Application and the 722 Application are incorporated by reference.

Technical Field of the Invention

The present invention relates generally to the field of telecommunications and, in particular, to a digital node for a hybrid fiber/coax network.

Background

Cable networks originally carried programming from a head end to subscribers over a network of coaxial cable. Over time, these networks have changed. Some cable networks now include fiber optic links as part of the network. This variety of cable network is colloquially referred to as a "hybrid fiber/coax" (HFC) network.

A hybrid fiber/coax network typically includes a head end that broadcasts programming over the network to subscribers in a downstream direction. The network includes two main portions. The first portion of the network is optical links that connect the head end with a number of geographically dispersed distribution nodes. These nodes are referred to as "optical distribution nodes" or "ODNs." At the ODNs, signals from the head end that carry the programming are converted from optical signals to electrical signals. The second portion of the network is coaxial links that connect the

ODNs with subscriber equipment. The electrical signals are transmitted to the subscriber equipment over the coaxial cable links.

In recent years, the cable industry has experimented with systems that allow for bi-directional communication between subscriber equipment and the head end. This allows for services such as video-on-demand, telephony and Internet traffic to be offered over a cable network. Typically the 5 to 42 MHZ frequency range is reserved for upstream transmission from customers to the head end. Frequencies between 50 MHZ and an upper limit, e.g., 750 MHZ or 850 MHZ, typically carry downstream transmissions.

The design of the reverse path for transporting data over a hybrid fiber/coax network is laced with difficult technical issues. First, many customers must communicate over a common coaxial cable. Interference between customers and noise ingress onto the cable can cause disruptions and errors in this communication. Ingress and other interference is especially a problem at the low frequencies typically prescribed for upstream communications. Transporting simultaneous data transmissions from many customers also introduces complexity into the system design.

In most current systems, the reverse path is implemented with one of a number of different analog modulation schemes, e.g., MCNS, Data Over Cable Service Interface Specification (DOCSIS). These schemes are complicated to implement due to strict timing requirements and complex modulation schemes. Other systems, such as AT&T's mini fiber node (mFNs), introduce other complexities into the return path.

For the reasons stated above, and for other reasons stated below which will become apparent to those skilled in the art upon reading and understanding the present specification, there is a need in the art for an improved digital data path for a hybrid fiber/coax network.

Summary

The above mentioned problems with telecommunications systems and other problems are addressed by the present invention and will be understood by reading and studying the following specification. A hybrid fiber/coax network is described which includes an optical distribution node that combines CSMA/CD error detection through frequency translation ("frequency turn-around") with modem functionality and data concentration.

In one embodiment, an optical distribution node is provided. The optical distribution node includes a laser transceiver that is coupleable to at least one fiber optic link. The optical distribution node communicates upstream and downstream digital data with the head end over the at least one fiber optic link. The optical distribution node further includes a data concentrator coupled to the laser transceiver. Further, for the at least one coaxial cable link, the optical distribution node includes a node modem. The node modem is coupled between the coaxial cable link and the data concentrator. The node modem demodulates upstream digital data for the data concentrator and modulates downstream digital data for transmission over the coaxial cable link. In another embodiment, the optical distribution node also includes a frequency translator coupled to the at least one coaxial cable link. The frequency translator receives and translates the upstream digital data from modems on the at least one coaxial cable link to a different carrier to provide a signal to the modems on the at least one coaxial cable link for collision detection.

Brief Description of the Drawings

Figure 1 is a block diagram of an embodiment of a hybrid fiber/coax network constructed according to the teachings of the present invention.

Figure 2 is a block diagram of another embodiment of an optical distribution node for a hybrid fiber/coax network according to the teachings of the present invention.

Figure 3 is a dataflow diagram that illustrates an embodiment of a layered implementation of communication protocol stacks for an optical distribution node according to the teachings of the present invention.

Detailed Description

The following detailed description refers to the accompanying drawings which form a part of the specification. The drawings show, and the detailed description describes, by way of illustration specific illustrative embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention. Other embodiments may be used and logical, mechanical and electrical changes may be made without departing from the scope of the present invention. The following detailed description is, therefore, not to be taken in a limiting sense.

I. Embodiment of a Hybrid Fiber/Coax Network

Figure 1 is a block diagram of an embodiment of a hybrid fiber/coax (HFC) network, indicated generally at 100, and constructed according to the teachings of the present invention. Network 100 is a bi-directional network that carries signals between head end or hub 102 and a number of modems 103-1-1, . . . , 103-M-N. Advantageously, network 100 includes a bi-directional data path that carries data in digital format, e.g., as Ethernet or other packets of digital data using Internet Protocol (IP), between modems 103-1-1, . . ., 103-M-N and head end 102.

Head end 102 is coupled to modems 103-1-1, . . ., 103-M-N over a combination of fiber optics and coaxial cable. Namely, head end 102 is coupled via fiber optic link 105 with optical distribution node 106. Fiber optic link 105 is used to carry digital data between head end 102 and modems 103-1-1, . . ., 103-M-N. In one embodiment, fiber optic link 105 includes two fiber optic cables: a first cable to carry upstream digital data from modems 103-1-1, . . ., 103-M-N to head end 102 and a second cable to carry downstream digital data from head end 102 to modems 103-1-1, . . ., 103-M-N. In another embodiment, fiber optic link 105 comprises a single fiber optic cable that uses wavelength division multiplexing or frequency division multiplexing to separate upstream and downstream digital data on fiber optic link 105.

Optical distribution node 106 is also coupled to coaxial cable links or branches 108-1, . . ., 108-M. Modems, represented by modems 103-1-1, . . ., 103-M-N, are selectively coupled to coaxial links 108-1, . . ., 108-M via directional couplers 110.

In one embodiment, the network 100 includes a transport path for digital data (bi-directional) and a transport path for other broadband services. For the other broadband services, network 100 combines signals from one or more sources at combiner 112 of head end 102. In one embodiment, combiner 112 receives analog and digital video signals. In another embodiment, combiner 112 also receives other data appropriate for transmission over network 100. Combiner 112 is coupled to optical transmitter 114. Optical transmitter 114 provides optical signals to optical distribution node 106 over fiber optic link 115. These optical signals are received by optical receiver 116 and coupled to coaxial cable links 108-1, . . ., 108-M through couplers 118-1, . . ., 118-M, respectively.

The bi-directional data path includes cable modem termination system 111 at head end 102. Termination system 111 includes network termination 113. Network termination 113 is coupled to public switched telephone network (PSTN) or backbone network 121 through headend switch or backbone transport adaptor 119. Termination system 111 is also coupled to optical transceiver 123. Optical transceiver 123 is coupled to optical transceiver 142 at optical distribution node 106 over fiber optic link 105.

In one embodiment, data on fiber optic links 105 and 115 is carried as base-band digital data using on-off keying. In another embodiment, data on fiber optic links 105 and 115 is carried using modulated carriers. Further, data on fiber optic links 105 and 115 is transmitted using the 100BaseT Ethernet protocol or any other standard or custom protocol.

Optical distribution node 106 includes data concentrator or switch 140 that is coupled to optical transceiver 142 and to at least one node modem 138-1, . . ., 138-M for each coaxial cable link 108-1, . . ., 108-M, respectively. Due to the similarity between the circuitry for each coaxial cable link 108-1, . . ., 108-M, only the path in optical distribution node 106 for coaxial cable link 108-1 is described here. However, it is

understood that the remaining coaxial cable links include similar circuitry in optical distribution node 106. Data concentrator or switch 140 also includes enterprise network drop 141. In one embodiment, drop 141 comprises a 10/100BaseT interface for a local area network. As fiber optical links 105 and 115 allow nodes 106 to penetrate deeper into network 100, drop 141 provides the advantage of allowing direct access to node 106 for an enterprise network.

In one embodiment, modems 103-1-1, . . ., 103-1-N launch upstream, digital data on coaxial cable link 108-1 by on-off-keying of one of a selected number of radio frequency carriers, e.g., f_1 in Figure 1, with digital data in the form of Ethernet packets. In other embodiments other modulation techniques are used, e.g., quadrature phase shift keying (QPSK), quadrature amplitude modulation (QAM), and other appropriate modulation techniques. Each modem 103-1-1, . . ., 103-1-N uses one of the select number of carriers. It is understood that any appropriate number of carriers can be used. In one embodiment, each of the select number of carriers falls in the frequency range below 42 MHZ. In other embodiments, at least a portion of the select number of carriers fall in a frequency range below the lower cutoff frequency for the downstream data path.

The bi-directional path of optical distribution node 106 includes frequency translator 124 that is coupled to coaxial cable link 108-1 through couplers 126 and 128. In one embodiment, coupler 126 comprises a directional coupler. Coupler 128 comprises a diplexer, a conventional 3 dB or other ratio coupler, or a directional coupler. The output of frequency translator 124 is coupled to coupler 128. Node modem 138-1 is also coupled to frequency translator 124 through coupler 126.

Frequency translator 124 provides a loopback mechanism to implement a collision detection protocol for the bi-directional path of network 100 on coaxial cable link 108-1. Frequency translator 124 translates modulated carriers, e.g., f_1, to other frequencies, e.g., f_2. Essentially, frequency translator 124 provides aggregate data received from all modems 103-1-1, . . ., 103-1-N on coaxial cable link 108-1 and node modem 138-1 back to modems 103-1-1, . . ., 103-1-N. Each modem 103-1-1, . . ., 103-1-N compares its transmitted data with the aggregate data to determine whether its data

was received at optical distribution node 106 without collision with other data or without corruption from ingress noise.

When a modem detects a collision, the modem provides a collision detection signal on another carrier. Modems 103-1-1, . . . , 103-M-N and node modem 138-1 further wait a randomly selected period of time to attempt retransmission of any corrupted data. Advantageously, this process allows network 100 to transmit upstream signals in the band below the downstream band despite ingress and other interference since interference looks like a collision to network 100 and data affected by the interference is automatically retransmitted. This also provides for bi-directional transport of data with symmetrical data rates between upstream and downstream data paths since the same frequency is used by modem 138-1 and modems 103-1-1, . . ., 103-M-N. The downstream signals from modem 138-1 are frequency translated by translator 124 such that the downstream transmissions are transported on, e.g., frequency f_2.

In one embodiment, modems 103-1-1, . . ., 103-M-N transmit Ethernet packets over network 100. It is understood that in other embodiments, the data transmitted over network 100 may comprise other formats.

In operation, digital data is transmitted between modems 103-1-1, . . ., 103-M-N and head end 102 over network 100. For example, digital data originating at modem 103-1-1 is provided to coaxial cable 108-1 on a modulated carrier. Frequency translator 124 translates the frequency of the modulated carrier and retransmits the data back to modem 103-1-1 with aggregate data from all modems on coaxial link 108-1 and downstream data from node modem 138-1. Modem 103-1-1 checks for collisions and if any, transmits a collision detect signal on a separate carrier and then waits a random amount of time and retransmits the data.

In the absence of a collision, the data is passed to data concentrator 140 and concentrated with data from other coaxial links. This data is passed to head end 102 over optical fiber link 105 by transmitter 142. At head end 102, the data is routed or switched to network 121.

Downstream data is transmitted from head end 102 over fiber optic link 115 to optical distribution node 106. At node 106, the downstream digital data is demodulated by node modem 138-1 and provided to frequency translator 124. The translated data is provided to modems 103-1-1, . . ., 103-1-N over coaxial cable link 108-1 with the aggregate upstream data from modems 103-1-1, . . ., 103-1-N. Modems 103-1-1, . . ., 103-1-N listen to frequency f_2 to receive downstream data from node modem 138-1. In this embodiment, modem 138-1 and modems 103-1-1, . . ., 103-M-N are substantially the same thus the available bandwidth in upstream and downstream directions is the same.

It is noted that in embodiments with more than one carrier frequency used for upstream communication on coaxial cable links, then additional node modems are coupled between frequency translator 124 and concentrator 140 for each coaxial cable link.

Node 106 of Figure 1 advantageously combines CSMA/CD error detection through frequency translation ("frequency turn-around") with modem functionality and data concentration. This combination of functionality is shown in Figure 3. Frequency turn-around is performed at the physical layer as indicated next to blocks 302 and 304. Bridging or modem functionality is provided at the data link layer as indicated at blocks 306 and 308. Further, routing functionality, e.g., concentration and switching, is provided at the network layer as indicated by blocks 310 and 312. In this manner, the frequency turn-around scheme does not require modulation or demodulation processes and is kept transparent to the hardware at node 106.

II. Another Embodiment of an Optical Distribution Node

Figure 2 is a block diagram of another embodiment of an optical distribution node, indicated generally at 206 and constructed according to the teachings of the present invention. In this embodiment, optical distribution node 206 advantageously provides for asymmetrical transport of data between a head end and modems. Node 206 includes transceiver 242 that coupled to the head end over a fiber optic link.

Transceiver 242 is coupled to data concentrator or switch 240. Data concentrator 240 is coupled to a plurality of node modems represented by node modem 238.

Node modem 238 provides upstream and downstream communication for digital data in node 106. In the downstream path, node modem 238 is coupled to a coaxial cable link through couplers 226 and 228, and diplexer 218. In the upstream direction, data is received from the coaxial cable link by node modem 238 via couplers 226 and 229, and diplexer 218. Couplers 226, 228 and 229 comprise directional couplers or conventional 3 dB or other ratio couplers. In this manner, the downstream data from node modem 238 is not frequency translated at frequency translator 224 and thus the downstream data is provided to the modems on a different carrier frequency. This allows for different data rates to be used in the downstream and the upstream directions.

Frequency translator 224 is coupled between couplers 229 and 228. Frequency translator 224 provides the same collision detection mechanism as described above with respect to frequency translator 124 of Figure 1 with the exception that downstream data is not included in the data that is provided back to the modems on the coaxial cable link.

In operation, digital data is provided on a bi-directional path through node 206 in a manner that allows different data rates to be used in the upstream and downstream directions. The downstream data is received at transceiver 242 and provided to node modem 238 through concentrator 240. This data is modulated on a downstream carrier and transmitted to modems through couplers 228, 226, and 218.

In the upstream direction, data is received from modems and frequency translated by frequency translator 224. This provides a collision detection mechanism for the upstream digital data path. If a collision is detected, then a collision detection signal is sent on another carrier and the modems wait a random amount of time and then attempt to retransmit.

If there is no collision, then node modem 238 receives the upstream data and provides it to the head end through data concentrator 240.

Node 206 of Figure 2 advantageously also combines CSMA/CD error detection through frequency translation ("frequency turn-around") with modem functionality and

data concentration. This combination of functionality is shown and described above with respect to Figure 3.

Conclusion

A hybrid fiber/coax network has been described with a digital return path. Essentially, data is modulated on carriers by modems and provided to an optical distribution node. A collision detection process is used by looping back aggregate data to the modems on a common coaxial cable link. The data from a number of coaxial cable links are concentrated and transmitted as digital data over a fiber optic connection to a head end or hub.

Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement which is calculated to achieve the same purpose may be substituted for the specific embodiment shown. This application is intended to cover any adaptations or variations of the present invention. For example, data can be transmitted in formats other than standard Ethernet formats. Further, any appropriate number of carrier frequencies can be used to carry digital data to the optical distribution nodes. Also, a part of the data can be transmitted on carriers that are located within or above the conventional downstream spectrum. For example, a portion of the data can be transmitted on unused carriers that are typically used for downstream channels. Further, carriers above the typical upper limit, e.g., above 750 MHZ or 850 MHZ, can also be used for upstream transmission. This allows the data path to carry more data than the conventional 5-42 MHZ band. Further, it is understood that a portion of the data path can be carried on frequencies between 42 and 850 MHZ if the spectrum is not allocated for downstream communication. In one embodiment, frequency turn-around at nodes 106 and 206 is accomplished according to ANSI/IEEE standard 802.3 (1996) (the "10BROAD36 standard"). In some embodiments, node modems are omitted from the optical distribution node. Further, it is understood that a frequency translator and node modem can be coupled to one or more coaxial cable links.

What is claimed is:

1. A hybrid fiber/coax network, comprising:

a head end;

at least one optical distribution node coupled to the head end over at least one fiber optic link;

at least one coaxial cable link, coupled to the at least one optical distribution node, that receives upstream digital data from and that provides downstream digital data to a plurality of modems;

wherein the upstream digital data is transmitted over the at least one coaxial cable link on at least one modulated carrier; and

wherein the optical distribution node has a bi-directional data path that includes:

a laser transceiver coupled to the at least one fiber optic link that communicates upstream and downstream digital data with the head end over the at least one fiber optic link;

a data concentrator coupled to the laser transceiver; and

a node modem coupled between the at least one coaxial cable link and the data concentrator that demodulates upstream digital data for the data concentrator and that modulates downstream digital data for transmission over the coaxial cable link.

2. The network of claim 1, wherein the bi-directional data path carries the upstream and the downstream digital data at substantially the same data rate.

3. The network of claim 1, wherein the bi-directional data path carries the upstream and the downstream digital data with different data rates.

4. The network of claim 1, wherein the node modem transmits downstream digital data on a modulated carrier with a different frequency from the upstream digital data.

5. The network of claim 1, and further including a frequency translator, coupled to the at least one coaxial cable link, that receives and translates the upstream digital data from the modems to a different carrier to provide a signal to the modems for collision detection.

6. The network of claim 5, wherein the node modem is coupled to the at least one coaxial cable link through the frequency translator such that the downstream digital data is frequency translated to the different carrier.

7. The network of claim 1, wherein the at least one fiber optic link comprises a first fiber optic link that carries upstream and downstream digital data and a second fiber optic link that carries downstream, broadband transmission.

8. The network of claim 7, wherein the first fiber optic link comprises separate fiber optic cables for upstream and downstream digital data.

9. The network of claim 7, wherein the first fiber optic link comprises a single fiber optic cable with separate wavelengths for upstream and downstream digital data.

10. The network of claim 1, wherein the upstream, digital data is carried on one of at least two modulated carriers.

11. The network of claim 5, wherein the modems transmit collision detection signals on a different modulated carrier when a collision is detected based on the signal from the frequency translator.

12. The network of claim 1, wherein the upstream, digital data comprises Ethernet packets.

13. The network of claim 1, wherein at least another portion of the upstream, digital data is transmitted over the plurality of coaxial cable links on modulated carriers above the frequency band for downstream transmissions.

14. The network of claim 1, wherein the laser transmitter transmits the upstream, digital data as one of base-band and modulated carrier transmission.

15. The network of claim 1, wherein the frequency translator is adapted to receive signals over the at least one coaxial cable link that are modulated with one of quadrature amplitude modulation (QAM), quadrature phase shifted keying (QPSK), and on-off keying.

16. The network of claim 1, wherein the data concentrator includes a network drop.

17. A hybrid fiber/coax network, comprising:

a head end;

a plurality of optical distribution nodes coupled to the head end over at least one fiber optic link;

a plurality of coaxial cable links selectively coupled to the plurality of optical distribution nodes;

wherein each of the optical distribution nodes includes a data concentrator coupled to a plurality of node modems to provide communication of upstream and downstream digital data between the head end and a plurality of modems coupled to coaxial cable links of the optical distribution node; and

wherein each optical distribution node includes a frequency translator coupled to each coaxial cable link to provide a frequency turn-around function at the physical layer to detect collisions on the at least one coaxial cable link.

18. The network of claim 17, wherein the bi-directional data path carries the upstream and the downstream digital data at substantially the same data rate.

19. The network of claim 17, wherein the bi-directional data path carries the upstream and the downstream digital data with different data rates.

20. The network of claim 17, wherein the node modem transmits downstream digital data on a modulated carrier with a different frequency from the upstream digital data.

21. The network of claim 17, wherein the at least one fiber optic link comprises a first fiber optic link that carries upstream and downstream digital data and a second fiber optic link that carries downstream, broadband transmissions.

22. The network of claim 19, wherein the first fiber optic link comprises separate fiber optic cables for upstream and downstream digital data.

23. The network of claim 19, wherein the first fiber optic link comprises a single fiber optic cable with separate wavelengths for upstream and downstream digital data.

24. The network of claim 17, wherein the upstream, digital data is carried on one of at least two modulated carriers.

25. The network of claim 17, wherein the modems transmit collision detection signals on a different modulated carrier when a collision is detected based on the signal from the frequency translator.

26. The network of claim 17, wherein the upstream digital data comprises Ethernet packets.

27. The network of claim 17, wherein the laser transmitter transmits the upstream digital data with one of base-band and modulated carriers.

28. The network of claim 17, wherein the frequency translator is adapted to receive signals over the at least one coaxial cable link that are modulated with one of quadrature amplitude modulation (QAM), quadrature phase shifted keying (QPSK), and on-off keying.

29. The network of claim 17, wherein the data concentrator includes a network drop.

30. An optical distribution node for a hybrid fiber/coax network, the optical distribution node comprising:

a laser transceiver coupleable to a fiber optic link that communicates upstream and downstream digital data with a head end of the hybrid fiber/coax network over at least one fiber optic link;

a data concentrator coupled to the laser;

at least one port coupleable to a coaxial cable link of the hybrid fiber/coax network; and

at least one node modem selectively coupled between the at least one port and the data concentrator that demodulates upstream digital data for the data concentrator and that modulates downstream digital data for transmission over the coaxial cable link.

31. The node of claim 30, and further comprising a frequency translator, coupled to the at least one port, that receives and translates the upstream digital data from a plurality of modems to a different carrier to provide a signal to the modems for collision detection.

32. The node of claim 30, wherein the upstream, digital data comprises Ethernet packets.

33. The node of claim 30, wherein the laser transmitter transmits the upstream, digital data with one of base-band and modulated carriers.

34. The node of claim 31, wherein the frequency translator also receives upstream, digital data on at least one additional carrier.

35. The node of claim 30, wherein the upstream and the downstream digital data are transmitted at substantially the same data rate.

36. The node of claim 30, wherein the upstream and the downstream digital data are transmitted with different data rates.

37. The node of claim 30, wherein the downstream digital data is transmitted on a modulated carrier with a different frequency from the upstream digital data.

38. A method for processing data in a bi-directional data path of a hybrid fiber/coax network, the method comprising:

receiving downstream, digital data at an optical distribution node on at least one optical link;

selectively transmitting the downstream, digital data on at least one coaxial cable link to a plurality of modems on a first carrier;

receiving, on the at least one coaxial cable link at the optical distribution node, upstream, digital data modulated on a second carrier;

translating the frequency of the second carrier to a third carrier;

retransmitting the upstream, digital data modulated on the third carrier on the at least one coaxial cable link;

checking at the optical distribution node for collision detection signals from the plurality of modems based on the retransmitted upstream, digital data; and

concentrating and transmitting the upstream, digital data to the head end over the at least one optical link.

39. The method of claim 38, wherein the frequency of the first carrier is the same as the frequency of the second carrier.

40. The method of claim 38, wherein the frequency of the first carrier is different from the frequency of the second carrier.

41. The method of claim 38, wherein checking for collision detection signals comprises monitoring a fourth carrier for collision detection signals.

42. The method of claim 38, wherein transmitting the concentrated, upstream, digital data comprises transmitting one of base-band and modulated carrier signals.

43. The method of claim 38, wherein receiving upstream, digital data comprises receiving Ethernet packets on a modulated carrier.

44. A hybrid fiber/coax network, comprising:

a head end;

at least one optical distribution node coupled to the head end over at least one fiber-optic link;

at least one coaxial cable link, coupled to the at least one optical distribution node, that receives upstream digital data from and that provides downstream digital data to a plurality of modems;

wherein at least a portion of the upstream digital data is transmitted over the at least one coaxial cable link on at least one modulated carrier below 42 MHz;

wherein the at least one optical distribution node includes at least one node modem coupled to a data concentrator to communicate upstream and downstream digital data between the head end and the plurality of modems; and

wherein the optical distribution node also includes a frequency translator that translates the upstream digital data from the plurality of modems to different carrier and retransmits the signal to the modems for collision detection.

45. An optical distribution node, comprising:

at least one frequency translator coupleable to a coaxial cable link to provide frequency turn-around functionality for collision detection on the coaxial cable link;

at least one node modem coupleable to the coaxial cable link;

a data concentrator coupled to the at least one node modem; and

a laser transceiver coupled to the data concentrator and coupleable to a fiber-optic link to communicate digital data to and from a head end.

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Abstract of the Disclosure

An optical distribution node is provided. The optical distribution node includes a laser transceiver that is coupleable to at least one fiber optic link. The optical distribution node communicates upstream and downstream digital data with the head end over the at least one fiber optic link. The optical distribution node further includes a data concentrator coupled to the laser transceiver. Further, for each of at least one coaxial cable link, the optical distribution node includes a frequency translator and a node modem. The frequency translator receives and translates the upstream digital data from modems on the at least one coaxial cable link to a different carrier to provide a signal to the modems on the at least one coaxial cable link for collision detection. The node modem is coupled between the coaxial cable link and the data concentrator. The node modem demodulates upstream digital data for the data concentrator and modulates downstream digital data for transmission over the coaxial cable link.

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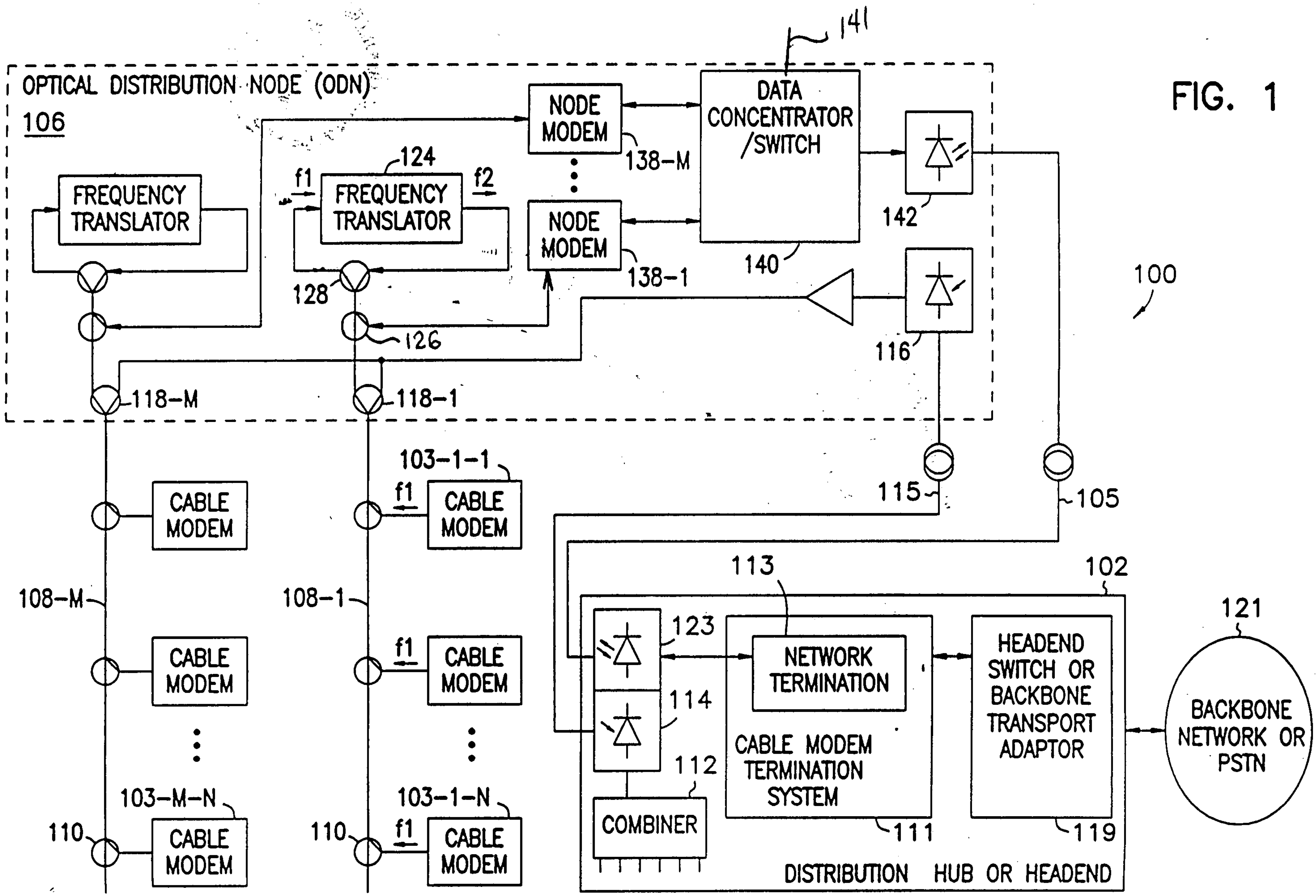


OPTICAL DISTRIBUTION NODE (ODN)
106
FREQUENCY TRANSLATOR
124
f1
FREQUENCY TRANSLATOR
f2
128
126
118-M
118-1
NODE MODEM
138-M
NODE MODEM
138-1
141
DATA CONCENTRATOR /SWITCH
140
142
116
100
103-1-1
CABLE MODEM
CABLE MODEM
CABLE MODEM
CABLE MODEM
CABLE MODEM
CABLE MODEM
f1
108-M
108-1
103-M-N
103-1-N
110
110
115
105
113
102
123
114
112
NETWORK TERMINATION
CABLE MODEM TERMINATION SYSTEM
111
HEADEND SWITCH OR BACKBONE TRANSPORT ADAPTOR
119
COMBINER
DISTRIBUTION HUB OR HEADEND
121
BACKBONE NETWORK OR PSTN

FIG. 1

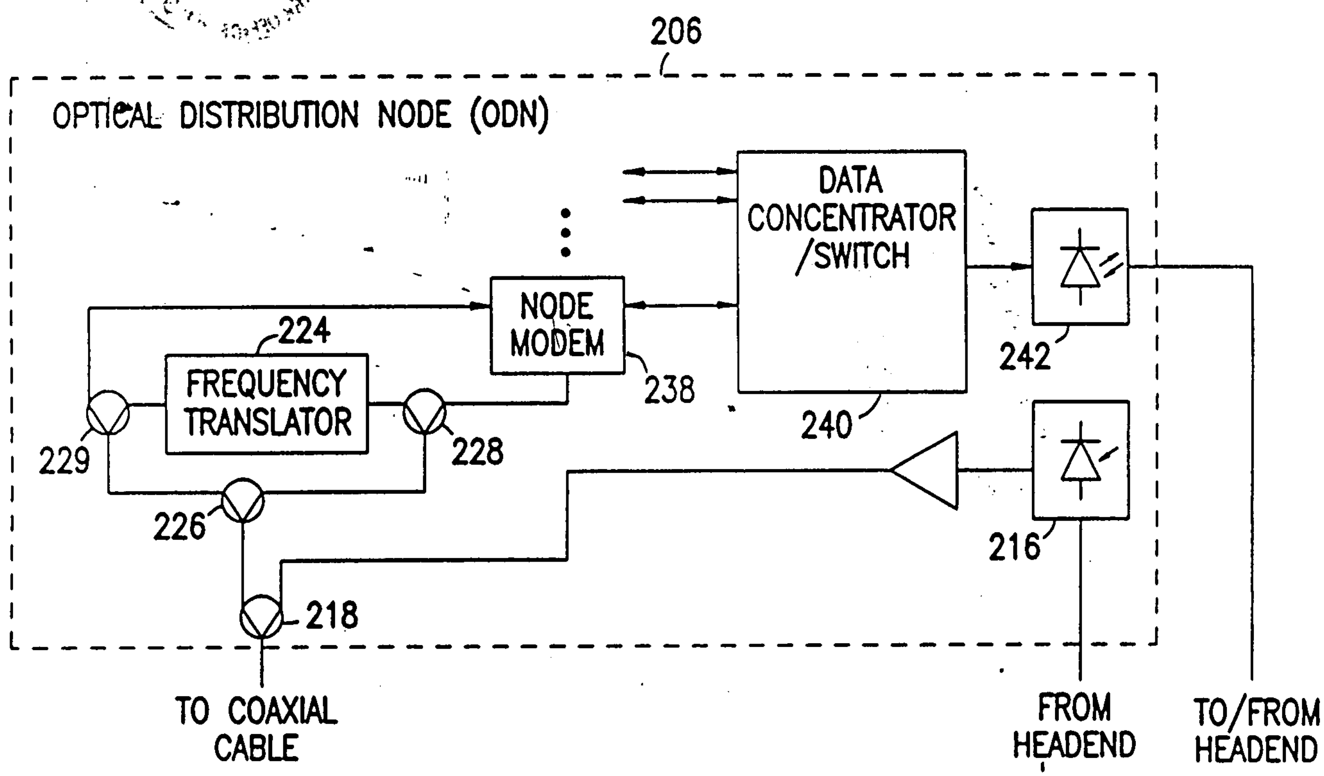
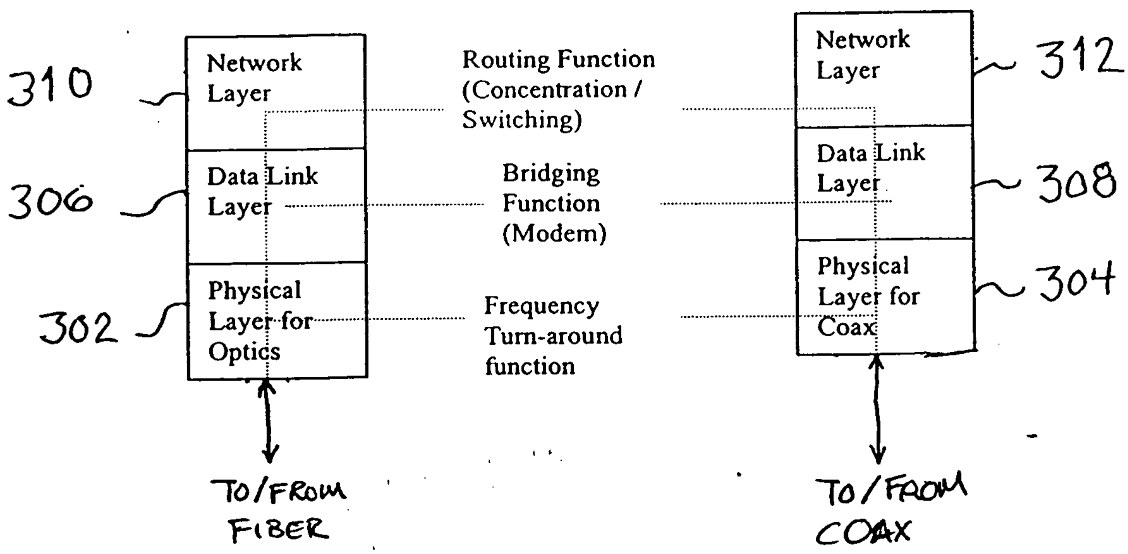

206
OPTICAL DISTRIBUTION NODE (ODN)
DATA CONCENTRATOR /SWITCH
NODE MODEM
224
FREQUENCY TRANSLATOR
229
228
238
240
242
226
216
218
TO COAXIAL CABLE
FROM HEADEND
TO/FROM HEADEND

FIG. 2



310
Network Layer
306
Data Link Layer
302
Physical Layer for Optics
TO/FROM FIBER
Routing Function (Concentration / Switching)
Bridging Function (Modem)
Frequency Turn-around function
Network Layer
312
Data Link Layer
308
Physical Layer for Coax
304
TO/FROM COAX

FIG. 3

POINT-TO-MULTIPOINT DIGITAL RADIO FREQUENCY TRANSPORT

Technical Field

The present invention is related to high capacity mobile communications systems, and more particularly to a point-to-multipoint digital micro-cellular communication system.

Background Information

With the widespread use of wireless technologies additional signal coverage is needed in urban as well as suburban areas. One obstacle to providing full coverage in these areas is steel frame buildings. Inside these tall shiny buildings (TSBs), signals transmitted from wireless base stations attenuate dramatically and thus significantly impact the ability to communicate with wireless telephones located in the buildings. In some buildings, very low power ceiling mounted transmitters are mounted in hallways and conference rooms within the building to distribute signals throughout the building. Signals are typically fed from a single point and then split in order to feed the signals to different points in the building.

In order to provide coverage a single radio frequency (RF) source needs to simultaneously feeds multiple antenna units, each providing coverage to a different part of a building for example. Simultaneous bi-directional RF distribution often involves splitting signals in the forward path (toward the antennas) and combining signals in the reverse path (from the antennas). Currently this can be performed directly at RF frequencies using passive splitters and combiners to feed a coaxial cable distribution network. In passive RF distribution systems, signal splitting in the forward path is significantly limited due to inherent insertion loss associated with the passive devices. Each split reduces the level of the signal distributed in the building thereby making reception, e.g. by cell phones, more difficult. In addition, the high insertion loss of coaxial cable at RF frequencies severely limits the maximum distance over which RF

signals can be distributed. Further, the system lacks any means to compensate for variations of insertion loss in each path.

Another solution to distributing RF signals in TSBs is taking the RF signal from a booster or base station, down converting it to a lower frequency, and distributing it via Cat 5 (LAN) or coaxial cable wiring to remote antenna units. At the remote antenna units, the signal is up converted and transmitted. While down-conversion reduces insertion loss, the signals are still susceptible to noise and limited dynamic range. Also, each path in the distribution network requires individual gain adjustment to compensate for the insertion loss in that path.

In another approach, fiber optic cables are used to distribute signals to antennas inside of a building. In this approach, RF signals are received from a bi-directional amplifier or base station. The RF signals directly modulate an optical signal, which is transported throughout the building as analog modulated light signals over fiber optic cable. Unfortunately, conventional systems using analog optical modulation transmission over optical fibers require highly sophisticated linear lasers to achieve adequate performance. Also, analog optical systems are limited in the distance signals can be transmitted in the building. Typically, this limitation is made worse due to the use of multimode fiber that is conventionally available in buildings. Multimode fiber is wider than single mode fiber and supports a number of different reflection modes so that signals tend to exhibit dispersion at the terminating end of the fiber. In addition, analog installation typically includes significant balancing when setting up the system. Further, RF levels in the system need to be balanced with the optical levels. If there is optical attenuation, the RF levels need to be readjusted. In addition, if the connectors are not well cleaned or properly secured, the RF levels can change.

Digitization of the RF spectrum prior to transport solves many of these problems. The level and dynamic range of digitally transported RF remains unaffected over a wide range of path loss. This allows for much greater distances to be covered, and eliminates the path loss compensation problem. However, this has been strictly a point-to-point

architecture. One drawback with digitally transported RF in a point-to-point architecture is the equipment and cost requirement. A host RF to digital interface device is needed for each remote antenna unit. In particular, for use within a building or building complex the number of RF to digital interface devices and the fiber to connect these devices is burdensome. For example, in a building having 20 floors, the requirement may include 20 host RF to digital interface devices for 20 remote antenna units, 1 per floor. In some applications more than one remote antenna unit per floor may be required. As a result, there is a need in the art for improved techniques for distributing RF signals in TSBs, which would incorporate the benefits of digital RF transport into a point-to-multipoint architecture.

Summary of the Invention

The above-mentioned problems with distributing RF signals within a building and other problems are addressed by the present invention and will be understood by reading and studying the following specification.

In one embodiment, a digital radio frequency transport system is provided. The transport system includes a digital host unit and at least two digital remote units coupled to the digital host unit. The digital host unit includes shared circuitry that performs bi-directional simultaneous digital radio frequency distribution between the digital host unit and the at least two digital remote units.

In another embodiment, a digital radio frequency transport system is provided. The transport system includes a digital host unit and at least one digital expansion unit coupled to the digital host unit. The transport system further includes at least two digital remote units, each coupled to one of the digital host unit and the digital expansion unit. The digital host unit includes shared circuitry that performs bi-directional simultaneous digital radio frequency distribution between the digital host unit and the at least two digital remote units.

In an alternate embodiment, a method of performing point-to-multipoint radio frequency transport is provided. The method includes receiving radio frequency signals at a digital host unit and converting the radio frequency signals to a digitized radio frequency spectrum. The method also includes optically transmitting the digitized radio frequency spectrum to a plurality of digital remote units. The method further includes receiving the digitized radio frequency spectrum at the plurality of digital remote units, converting the digitized radio frequency spectrum to analog radio frequency signals and transmitting the analog radio frequency signals via a main radio frequency antenna at each of the plurality of digital remote units.

Brief Description of the Drawings

Figure 1 is an illustration of one embodiment of a point-to-multipoint communication system according to the teachings of the present invention.

Figure 2 is a block diagram of one embodiment of a communication system according to the teachings of the present invention.

Figure 3 is a block diagram of another embodiment of a communication system according to the teachings of the present invention.

Figure 4 is a block diagram of one embodiment of a digital host unit according to the teachings of the present invention.

Figure 5 is a block diagram of one embodiment of a digital remote unit according to the teachings of the present invention.

Figure 6 is a block diagram of one embodiment of a digital expansion unit according to the teachings of the present invention.

Figure 7 is a block diagram of one embodiment of a microcell base station according to the teachings of the present invention.

Figure 8 is an illustration of one embodiment of an overflow algorithm for a channel summer according to the teachings of the present invention.

Detailed Description

In the following detailed description of the preferred embodiments, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration specific embodiments in which the invention may be practiced. It is to be understood that other embodiments may be utilized and structural changes may be made without departing from the scope of the present invention.

Figure 1 is an illustration of one exemplary embodiment of a point-to-multipoint digital transport system shown generally at 100 and constructed according to the teachings of the present invention. The point-to-multipoint digital transport system 100 is shown distributed within a complex of tall shiny buildings (TSBs) 2. Although system 100 is shown in a complex of TSBs 2, it is understood that system 100 is not limited to this embodiment. Rather, system 100 in other embodiments is used to distribute signals in a single building, or other appropriate structure or indoor or outdoor location that exhibits high attenuation to RF signals. Advantageously, system 100 uses digital summing of digitized RF signals from multiple antennas to improve signal coverage in structures, such as TSBs.

Point-to-multipoint digital transport of RF signals is accomplished through a network of remote antenna units or digital remote units 40 and 40' and a digital host unit 20, which interfaces with a wireless network 5 which is coupled to the public switched telephone network (PSTN), or a mobile telecommunications switching office (MTSO) or other switching office/network. System 100 operates by transporting RF signals digitally over fiber optic cables. Signals received at DHU 20 are distributed to multiple DRUs 40 and 40' to provide coverage throughout a building complex. In addition, signals received at each of the DRUs 40 and 40' are summed together at the DHU 20 for interface to a wireless network.

In one embodiment, digital expansion unit DEU 30 is situated between the DHU 20 and one or more DRUs. In the forward path, DEU 30 expands the coverage area by

splitting signals received from DHU 20 to a plurality of DRUs 40'. In the reverse path, DEU 30 receives signals from a plurality of DRUs 40', digitally sums the signals together and transports them to a DHU 20 or another DEU such as 30. This system allows for successive branching of signals using DEUs 30 and expanded coverage to multiple DRUs 40 and 40'. This system provides an efficient way of providing signal coverage for wireless communication without added attenuation loss and distance constraint found with analog systems. By using DEUs 30, antennas can be placed further from DHU 20 without adversely affecting signal strength since shorter fiber optic cables can be used.

Digital transport system 100 includes a wireless interface device (WID) 10 that provides an interface to a wireless network. In one embodiment, the WID 10 includes either conventional transmitters and receivers or all digital transmitter and receiver equipment, and interface circuitry to a mobile telecommunications switching office (MTSO). In one embodiment, the wireless interface device 10 is coupled to an MTSO via a T1 line and receives and transmits signals between the MTSO and the DHU 20. In another embodiment, the wireless interface device 10 is coupled to the public switched telephone network (PSTN). In one embodiment, WID 10 comprises a base station and connects directly to DHU 20 via coaxial cables. In another embodiment, WID 10 comprises a base station and wirelessly connects to DHU 20 via a bi-directional amplifier that is connected to an antenna. In one embodiment, the antenna is an outdoor antenna.

WID 10 communicates signals between wireless units and the wireless network via digital remote units DRUs 40 and 40'. WID 10 is coupled to DHU 20. The DHU 20 is coupled to at least one digital expansion unit DEU 30 and a plurality of DRUs 40. In addition, DEU 30 is coupled to a plurality of DRUs 40'. The DHU 20 receives RF signals from WID 10 and converts the RF signals to digital RF signals. DHU 20 further optically transmits the digital RF signals to multiple DRUs 40 either directly or via one or more DEUs 30.

Each DRU 40 and 40' is connected through a fiber optic cable (or optionally another high bandwidth carrier) to transport digital RF signals to one of DHU 20 or DEU 30. In one embodiment, the fiber optic cable comprises multimode fiber pairs coupled between the DRUs 40 and the DHU 20, between the DRUs 40 and 40' and the DEUs 30 and between the DEUs 30 and the DHU 20. In one embodiment, the DEU 30 is coupled to the DHU 20 via single mode fiber and the DEU 30 is coupled to the DRUs 40' via multimode fiber pairs. Although, transport system 100 has been described with fiber optic cable other carriers may be used, e.g., coaxial cable.

In another embodiment, the DHU 20 is coupled to the DRUs 40 by a direct current power cable in order to provide power to each DRU 40. In one embodiment, the direct current power cable delivers 48 VDC to each DRU 40 connected to the DHU 20. In another embodiment, the DEU 30 is coupled to DRUs 40' by a direct current power cable to provide power to each DRU 40'. In one embodiment, the direct current power cable delivers 48 VDC to each DRU 40' connected to the DEU 30. In an alternate embodiment, DRUs 40 and 40' are connected directly to a power supply. In one embodiment, the power supply provides DC power to the DRUs 40 and 40'. In an alternate embodiment, the power supply provides AC power to the DRUs 40 and 40'. In one embodiment, DRUs 40 and 40' each include an AC/DC power converter.

Both DHU 20 and DEU 30 split signals in the forward path and sum signals in the reverse path. In order to accurately sum the digital signals together at DHU 20 or DEU 30 the data needs to come in to the DHU 20 or DEU 30 at exactly the same rate. As a result all of the DRUs 40 and 40' need to be synchronized so that their digital sample rates are all locked together. Synchronizing the signals in time is accomplished by locking everything to the bit rate over the fiber. In one embodiment, the DHU 20 sends out a digital bit stream and the optical receiver at the DEU 30 or DHU 40 detects that bit stream and locks its clock to that bit stream. In one embodiment, this is being accomplished with a multiplexer chip set and local oscillators, as will be described below. Splitting and combining the signals in a digital state avoids the combining and

splitting losses experienced with an analog system. In addition, transporting the digital signals over multimode fiber results in a low cost transport system that is not subject to much degradation.

The down-conversion and up-conversion of RF signals are implemented by mixing the signal with a local oscillator (LO) at both the DRUs and the DHU. In order for the original frequency of the RF signal to be restored, the signal must be up-converted with an LO that has exactly the same frequency as the LO that was used for down conversion. Any difference in LO frequencies will translate to an equivalent end-to-end frequency offset. In the embodiments described, the down conversion and up conversion LOs are at locations remote from one another. Therefore, in one preferred embodiment, frequency coherence between the local and remote LO's is established as follows: at the DHU end, there is a 142 MHz reference oscillator which establishes the bit rate of 1.42 GHz over the fiber. This reference oscillator also generates a 17.75 MHz reference clock which serves as a reference to which LO's at the DHU are locked.

At each of the DRUs, there is another 17.75 MHz clock, which is recovered from the optical bit stream with the help of the clock and bit recovery circuits. Because this clock is recovered from the bit stream generated at the host, it is frequency coherent with the reference oscillator at the host. A reference 17.75 MHz clock is then generated to serve as a reference for the remote local oscillators. Because the remote recovered bit clock is frequency coherent with the host master clock, the host and remote reference clocks, and any LO's locked to them, are also frequency coherent, thus ensuring that DHU and DRU LO's are locked in frequency. It is understood that in other embodiments the bit rate over the fiber may vary and the frequency of the clocks will also vary.

Figure 2 is a block diagram of one embodiment of a communication system, shown generally at 200 and constructed according to the teachings of the present invention. In this embodiment, a digital host unit (DHU) 220 is coupled to a bi-directional amplifier (BDA) 211. The BDA 211 receives communication signals from a

wireless interface device (WID) and transports the communication signals as RF signals to the DHU 220 and receives RF signals from DHU 220 and transmits the RF signals to the WID. The DHU 220 receives RF signals from the BDA 211 and digitizes the RF signals and optically transmits the digital RF signals to multiple DRUs via transmission lines 214-1 to 214-N. DHU 220 also receives digitized RF signals over transmission lines 216-1 to 216-N from a plurality of DRUs either directly or indirectly via DEUs, reconstructs the corresponding analog RF signals, and applies them to BDA 211. In one embodiment, DHU 220 receives signals directly from a plurality N of DRUs. The signals are digitally summed and then converted to analog signals and transmitted to BDA 211. In another embodiment, DHU 220 receives signals from one or more DEUs and one or more DRUs directly. Again, the signals are all digitally summed and then converted to analog signals and transmitted to BDA 211. The signals received via transmission lines 216-1 to 216-N may be received directly from a DRU or signals that are received by a DEU and summed together and then transported via 216-1 to 216-N to DHU 220 for additional summing and conversion for transport to BDA 211. DEUs provide a way to expand the coverage area and digitally sum signals received from DRUs or other DEUs for transmission in the reverse path to other DEUs or DHU 220. In one embodiment, transmission lines 214-1 to 214-N and 216-1 to 216-N comprise multimode fiber pairs. In an alternate embodiment, each fiber pair is replaced by a single fiber, carrying bi-directional optical signals through the use of wavelength division multiplexing (WDM). In an alternate embodiment, transmission lines 214-1 to 214-N and 216-1 to 216-N comprise single mode fibers. In one embodiment, N is equal to six. In an alternate embodiment, the number of transmission lines in the forward path direction 214-1 to 214-N is not equal to the number of transmission lines in the reverse path direction 216-1 to 216-N.

Figure 3 is a block diagram of an alternate embodiment of a communication system shown generally at 300 and constructed according to the teachings of the present invention. Communication system 300 includes a base station 310 coupled to a DHU

320. Base station 310 includes conventional transmitters and receivers 323 and 328, respectively, and conventional radio controller or interface circuitry 322 to an MTSO or telephone switched network. DHU 320 is coupled to base station 310. DHU 320 is also coupled to transmission lines 314-1 to 314-M, which transmit in the forward path direction and transmission lines 316-1 to 316-M, which transmit in the reverse path direction.

DHU 320 essentially converts the RF spectrum to digital in the forward path and from digital to analog in the reverse path. In the forward path, DHU 320 receives the combined RF signal from transmitters 323, digitizes the combined signal and transmits it in digital format over fibers 314-1 to 314-M, which are connected directly to a plurality of DRUs or indirectly to one or more DRUs via one or more DEUs.

In one embodiment, DHU 320 receives signals directly from a plurality M of DRUs. The signals are digitally summed and then converted to analog signals and transmitted to base station 310. In another embodiment, DHU 320 receives signals from one or more DEUs and one or more DRUs directly. Again, the signals are all digitally summed and then converted to analog signals and transmitted to base station 310. The signals received via transmission lines 316-1 to 316-M may be received directly from a DRU or signals that are received by a DEU and summed together and then transported via 316-1 to 316-M to DHU 320 for additional summing and conversion for transport to base station 210. DEUs provide a way to expand the coverage area by splitting signals in the forward path and digitally summing signals received from DRUs or other DEUs in the reverse path for transmission upstream to other DEUs or a DHU. In the reverse path, DHU 320 also receives digitized RF signals over fibers 316-1 to 316-M from a plurality of DRUs, either directly or indirectly via DEUs, reconstructs the corresponding analog RF signal, and applies it to receivers 328.

In one embodiment, transmission lines 314-1 to 314-M and 316-1 to 316-M comprise multimode fiber pairs. In an alternate embodiment, each fiber pair is replaced by a single fiber, carrying bi-directional optical signals through the use of wavelength

division multiplexing (WDM). In an alternate embodiment, transmission lines 314-1 to 314-M and 316-1 to 316-M comprise single mode fibers. In one embodiment, M is equal to six. In an alternate embodiment, the number of transmission lines in the forward path direction 314-1 to 314-M is not equal to the number of transmission lines in the reverse path direction 316-1 to 316-M.

Referring now to FIG. 4, there is shown one embodiment of a DHU 420 constructed according to the teachings of the present invention. DHU 420 includes an RF to digital converter 491 receiving the combined RF signals from a wireless interface device such as a base station, BDA or the like. RF to digital converter 491 provides a digitized traffic stream that is transmitted to multiplexer 466. Multiplexer 466 converts the parallel output of the A/D converter into a framed serial bit stream. At the output of the multiplexer is a 1 to P fan out buffer 407, which splits the digital signal P ways. There are P optical transmitters 431-1 to 431-P one feeding each of the P optical transmission lines 414-1 to 414-P. The digitized signals are applied to fibers 414-1 to 414-P for transmission to corresponding DRUs either directly or via DEUs. In one embodiment, P is equal to 6.

In one embodiment, DHU 420 includes an amplifier 450 that receives the combined RF signal from a wireless interface device such as a base station or BDA. The combined RF signal is amplified and then mixed by mixer 452 with a signal received from local oscillator 468. Local oscillator 468 is coupled to reference oscillator 415. In one embodiment the local oscillator is coupled to a frequency divider circuit 470, which is in turn coupled to reference oscillator 415. The local oscillator is locked to the reference oscillator 415 as a master clock so that the down conversion of the RF signals is the same as the up conversion. The result is end to end, from DHU to DRU, or DHU to one or more DEUs to DRU, no frequency shift in the signals received and transmitted. The local oscillator 463 is also coupled to a synthesizer circuit 476.

The output signal of mixer 452 is provided to amplifier 454 amplified and then filtered via intermediate frequency (IF) filter 456. The resultant signal is the combined

RF signal converted down to an IF signal. The IF signal is mixed with another signal originating from the reference oscillator 415 via mixer 460. The output of mixer 460 is summed together at 462 with a signal produced by field programmable gate array (FPGA) 467. The output is then converted from an analog signal to a digital signal via analog/digital (A/D) converter 464 once converted the digital RF signal is applied to multiplexer 466. In one embodiment, the A/D converter 464 is a 14-bit converter handling a 14-bit signal. In other embodiments, the A/D converter 464 may be of any size to accommodate an appropriate signal. In one embodiment, the input signal from FPGA 467 is a dither signal from dither circuit 462 that adds limited out of band noise to improve the dynamic range of the RF signal.

In one embodiment, DHU 420 includes an alternating current to digital current power distribution circuit 6 that provides direct current power to each of the DRUs coupled to DHU 420.

DHU 420 further includes a plurality of digital optical receivers 418-1 to 418-P in the reverse path. Receivers 418-1 to 418-P each output an electronic digital signal, which is applied to clock and bit recovery circuits 445-1 to 445-P, respectively, for clock and bit recovery of the electronic signals. The signals are then applied to demultiplexers 441-1 to 441-P, respectively, which extract the digitized signals generated at the DRUs, as will be explained in detail below. Demultiplexers 441-1 to 441-P further extract alarm (monitoring) and voice information framed with the digitized signals. The digitized signals output at each demultiplexer 441-1 to 441-P are then applied to FPGA 467 where the signals are summed together and then applied to digital to RF converter 495. Converter 495 operates on the sum of the digitized signals extracted by demultiplexers 441-1 to 441-P, reconstructing baseband replicas of the RF signals received at all the digital remote units. The baseband replicas are then up-converted to their original radio frequency by mixing with a local oscillator 482 and filtering to remove image frequencies. Local oscillator 482 is coupled to synthesizer 476 and reference oscillator as discussed with respect to local oscillator 468 above.

In one embodiment, digital to RF converter 495 includes digital to analog (D/A) converter 484 coupled to an output of FPGA 467 the digitized RF signals are converted to analog RF signals and then mixed with a signal from reference oscillator 415 by mixer 492. The signal is then filtered by IF filter 490 and amplified by amplifier 488. The resultant signal is then mixed with a signal from local oscillator 482 and then applied to RF filter 484, amplifier 480 and RF filter 478 for transmission by a wireless interface device such as a BDA or base station.

In one embodiment, FPGA 467 includes an alarm/control circuit 474, which extracts overhead bits from DRUs to monitor error and alarm information. In one embodiment, the FPGA 467 includes a summer 498, which mathematically sums together the digital RF signals received from fibers 416-1 to 416-P. In another embodiment FPGA includes an overflow algorithm circuit 486 coupled to the output of summer 486. The algorithm circuit 496 allows the summed digital RF signals to saturate and keep the summed signal within a defined number of bits. In one embodiment, the algorithm circuit includes a limiter. In one embodiment, the RF signals are 14-bit signals and when summed and limited by summer 498 and overflow algorithm 496 result in a 14-bit output signal.

For example, in one embodiment each of the digital RF signals received from fibers 416-1 to 416-P, where P is equal to 6, comprise 14 bit inputs. All of those 6 different 14 bit inputs then go into summer 498. In order to allow for overflow, at least 17 bits of resolution is needed in the summer 498 to handle a worst-case scenario when all 6 of the 14 bit inputs are at full scale at the same time. In this embodiment, a 17-bit wide summer 498 is employed to handle that dynamic range. Coming out of summer 498 is needed a 14-bit signal going in the reverse path. In one embodiment, an algorithm circuit 496 for managing the overflow is implemented. In one embodiment, the summer and 498 and overflow algorithm 496 are included in FPGA 467. In one embodiment, overflow algorithm 496 acts like a limiter and allows the sum to saturate and keeps the summed signal within 14 bits. In an alternate embodiment, overflow

algorithm circuit 496 controls the gain and scales the signal dynamically to handle overflow conditions.

Figure 8 illustrates one embodiment of an algorithm 863 for a channel summer 865 in order to limit the sum of input signals 0 to 5 to 14 bits. In this embodiment, input signals 0 to 5 comprise 6 signals that are summed together by summer 865. The sum of input signals 0 to 5 is reduced to a signal having 14 bits or less by the algorithm 863. It is understood that the algorithm 865 is by example and is not meant to restrict the type of algorithm used to limit the sum of signals 0 to 5 to 14 bits or less.

For example, when the sum of the 6 input signals 0 to 5 is greater than or equal to 13FFBh then the sum is divided by 6 for a signal that is 14 bits or less. When the sum of the 6 input signals 0 to 5 is greater than 13FFBh but less than or equal to FFFCh then the sum is divided by 5 for a signal that is 14 bits or less. When the sum of the 6 input signals 0 to 5 is greater than FFFCh but less than BFFDh then the sum is divided by 4 for a signal that is 14 bits or less. When the sum of the 6 input signals 0 to 5 is greater BFFDh but less than 7FFEh then the sum is divided by 3 for a signal that is 14 bits or less. Finally, when the sum of the 6 input signals 0 to 5 is greater than 7FFEh but less than or equal to 3FFFh then the sum is divided by 2 for a signal that is 14 bits or less.

Figure 5 is a block diagram of one embodiment of a digital remote unit (DRU) 540 constructed according to the teachings of the present invention. A digital optical receiver 501 receives the optical digital data stream transmitted from a DHU directly or via a DEU. Receiver 501 converts the optical data stream to a corresponding series of electrical pulses. The electrical pulses are applied to clock and bit recovery circuit 503. The series of electrical pulses are then applied to demultiplexer 505. Demultiplexer 505 extracts the digitized traffic signals and converts the signals from serial to parallel.. The output parallel signal is then applied to digital to RF converter 595 for conversion to RF and transmission to duplexer 547. RF converter 595 is connected to the main antenna

599 through a duplexer 547. Accordingly, radio frequency signals originating from a wireless interface device are transmitted from main antenna 547.

In one embodiment, digital to RF converter 595 includes a digital-to-analog (D/A) converter 509, which reconstructs the analog RF signal and applies it to IF 504 and amplifier 506. The analog signal is mixed with an output signal of reference oscillator 515 by mixer 502. The output of amplifier 506 is mixed with a signal from local oscillator 519 that locks the RF signal with the return digital signal via reference oscillator 515 that is coupled to local oscillator 519. In one embodiment, the reference oscillator is coupled to frequency divider 517 that in turn is coupled to local oscillators 519 and 529. The local oscillators 519 and 529 are also coupled to synthesizer 521 that is coupled to programmable logic device 525.

RF signals received at main antenna 599 are passed through duplexer 547 to RF to digital converter 593. The RF signals are converted to digital signals and then applied to multiplexer 536 converted from parallel-to-serial and optically transmitted via optical transmitter 532 to a DEU or DHU.

In one embodiment, RF to digital converter 593 includes a first amplifier 543 that receives RF signals from duplexer 547, amplifies the signals and transmits them to digital attenuator 539. In one embodiment, amplifier 543 is a low noise amplifier. Digital attenuator 539 receives the amplified signals and digitally attenuates the signal to control the levels in case of an overload situation. RF to digital converter 593 further includes a second amplifier 537, which receives the attenuated signals, amplifies the signals and applies the amplified signals to mixer 535. Mixer 535 mixes the amplified signals with a signal received from local oscillator 529. The resultant signals are applied to a third amplifier 533 an IF filter 548 and a fourth amplifier 546 in series to down convert to an IF signal. The IF signal is then mixed with a signal from reference oscillator 515 and the mixed signal is summed with a signal from dither circuit 527. The resultant signal is applied to analog-to-digital converter 538 and converted to a digital signal. The output digital signal is then applied to a multiplexer 536. In one

embodiment, the multiplexer 536 multiplexes the signal together with a couple of extra bits to do framing and control information. In one embodiment, multiplexer 536, clock and bit recovery circuit and demultiplexer 505 comprise a multiplexer chip set.

Programmable logic circuit 525 programs synthesizer 521 for the reference oscillator and for the up and down conversion of local oscillators 519 and 529. The programmable logic circuit 525 looks for error conditions, for out of lock conditions on the oscillators and reports error modes and looks for overflow condition in the A/D converter 538. If an overflow condition occurs the programmable logic circuit 525 indicates that you are saturating and adds some extra attenuation at digital attenuator 539 in order to reduce the RF signal levels coming in from RF antenna 599 and protect the system from overload.

In one embodiment, DRU 540 includes an internal direct current power distribution system 5. In one embodiment, the distribution system receives 48 VDC and internally distributes 3 outputs of +3.8V, +5.5V and +8V.

Figure 6 is a block diagram of one embodiment of a digital expansion unit (DEU) 630 constructed according to the teachings of the present invention. DEU 630 is designed to receive optical signals and transmit optical signals. An optical receiver 651 receives digitized RF signals and transmits them to clock and bit recovery circuit 653 that performs clock and bit recovery to lock the local clock and clean up the signal. The signals are then split into X RF digital signals by 1 to X fan out buffer 607. The signals are then transmitted via optical transmitters 655-1 to 655-X to X receiving units such as DEUs or DRUs. The X receiving units may be any combination of DEUs or DRUs. In one embodiment, X is equal to six.

DEU 630 also includes optical receivers 669-1 to 669-X, which receive digitized RF signals directly from DRUs or indirectly via DEUs. In operation the signals are received, applied to clock and bit recovery circuits 673-1 to 673-X respectively to lock the local clock and clean up the signals and then applied to demultiplexers 671-1 to 671-X. Demultiplexers 671-1 to 671-X each extract the digitized traffic and apply the

samples to field programmable gate array 661. The signals are summed together digitally and transmitted to multiplexer 657, which mulitplexes the signal together with a couple of extra bits to do framing and control information. In addition, the multiplexer 657 converts the signals parallel to serial. The signals are then applied to optical transmitter 659 for further transmission. In one embodiment, the signals are directly transmitted to a DHU or indirectly via one or more additional DEUs.

In one embodiment, the FPGA 661 includes summer 665, which mathematically sums together the digital RF signals received from demultiplexers 671-1 to 671-X. In another embodiment, FPGA 661 includes an overflow algorithm circuit 663 coupled to the output of summer 665. The algorithm circuit 663 allows the summed digital RF signals to saturate and keep the summed signal within a defined number of bits. In one embodiment, the algorithm circuit includes a limiter. In one embodiment, the RF signals are 14-bit signals and when summed and limited by summer 665 and overflow algorithm 663 result in a 14-bit output signal.

In one embodiment, DEU 630 includes an alternating current to digital current power distribution circuit 7 that provides direct current power to each of the DRUs coupled to DEU 630.

In an alternate embodiment, the digital host unit (DHU) and wireless interface device (WID) are located some distance from the building being served. The DHU in the building is replaced by a DEU, and the link between that DEU and the remotely located DHU is via single mode fiber. Figure 7 is a block diagram of this embodiment. A microcell base station shown generally at 700 includes conventional transmitters and receivers 723 and 728, respectively, and conventional radio controller or interface circuitry 722. In the forward path, a DHU 767 receives the combined RF signal from transmitters 723, digitizes the combined signal and transmits it in digital format over single mode fiber to a DEU. In the reverse path, DHU 767 receives digitized RF signal from a DEU, reconstructs the corresponding analog RF signal, and applies it to receivers 728.

In another alternate embodiment, the wireless interface device (WID) is a software defined base station, and the interface between the DHU and WID takes place digitally, eliminating the need for the RF to digital conversion circuitry in the DHU.

Conclusion

A digital radio frequency transport system has been described. The transport system includes a digital host unit and at least two digital remote units coupled to the digital host unit. The digital host unit includes shared circuitry that performs bi-directional simultaneous digital radio frequency distribution between the digital host unit and the at least two digital remote units.

In addition, a digital radio frequency transport system has been described. The transport system includes a digital host unit and at least one digital expansion unit coupled to the digital host unit. The transport system further includes at least two digital remote units, each coupled to one of the digital host unit and the digital expansion unit. The digital host unit includes shared circuitry that performs bi-directional simultaneous digital radio frequency distribution between the digital host unit and that at least two digital remote units.

Further, a method of performing point-to-multipoint radio frequency transport has been described. The method includes receiving analog radio frequency signals at a digital host unit and converting the analog radio frequency signals to digitized radio frequency signals. The method also includes splitting the digitized radio frequency signals into a plurality of a digital radio frequency signals and optically transmitting the digital radio frequency signals to a plurality of digital remote units. The method further includes receiving the digital radio frequency signals at a plurality of digital remote units, converting the digital radio frequency signals to analog radio frequency signals and transmitting the signals via a main radio frequency antenna at each of the plurality of digital remote units.

Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement which is calculated to achieve the same purpose may be substituted for the specific embodiments shown. For example, a digital remote unit is not limited to the receipt and summing and splitting and transmitting of digitized radio frequency signals. In other embodiments, the digital host unit is capable of receiving and summing analog radio frequency signals in addition to or instead of digitized radio frequency signals. As well, the digital host unit is capable of splitting and transmitting analog radio frequency signals in addition to or instead of digitized radio frequency signals. This application is intended to cover any adaptations or variations of the present invention. Therefore, it is intended that this invention be limited only by the claims and the equivalents thereof.

What is claimed is:

1. A digital radio frequency transport system, comprising:

a digital host unit; and

at least two digital remote units coupled to the digital host unit, wherein the digital host unit includes shared circuitry that performs bi-directional simultaneous digital radio frequency distribution between the digital host unit and the at least two digital remote units.

2. The system of claim 1, further comprising a wireless interface device coupled to the digital host unit.

3. The system of claim2, wherein the wireless interface device comprises a base station that couples directly to the digital host unit via coaxial cables.

4. The system of claim 2, wherein the wireless interface device comprises a base station that wirelessly connects to the digital host unit via bi-directional amplifier that is coupled to an antenna.

5. The system of claim 1, wherein the at least two digital remote units each include a main radio frequency antenna which transmits and receives radio frequency signals.

6. The system of claim 1, wherein the digital host unit includes a radio frequency to digital converter that converts a main radio frequency signal to a digitized radio frequency signal.

7. The system of claim 6, wherein the digital host unit further includes a multiplexer which splits the digitized radio frequency signal into at least two digital signals for optical transmission to the at least two digital remote units.

8. The system of claim 1, wherein the digital host unit includes local oscillators coupled to a reference oscillator for synchronization of the radio frequency signal in the forward direction and in the reverse direction.

9. The system of claim 1, wherein the digital host unit is coupled to each of the at least two digital remote units by a multimode fiber pair.

10. The system of claim 1, wherein the digital host unit includes:

at least two optical receivers each coupled to one of the at least two digital remote units;

at least two clock and bit recover circuits each coupled to an output of one of the at least two optical receivers; and

at least two demultiplexers each coupled to an output of one of the at least two clock and bit recovery circuits.

11. The system of claim 10, wherein the digital host unit further includes a field programmable gate array coupled to an output of each of the at least two demultiplexers, wherein the field programmable gate array receives a digital radio frequency signal from each of the at least two demultiplexers.

12. The system of claim 11, wherein the field programmable gate array includes a summer that sums together the digital radio frequency signals from each of the at least two demultiplexers.

13. The system of claim 12, wherein the field programmable gate array further includes an overflow algorithm circuit, which allows the summed digital radio frequency signals to saturate and keeps the summed signal within a defined number of bits.

14. The system of claim 13, wherein the overflow algorithm circuit comprises a limiter.

15. The system of claim 12, wherein the digital host unit further includes a digital to radio frequency converter coupled to an output of the field programmable gate array, wherein the radio frequency converter receives the summed digital radio frequency signal and converts it to an analog radio frequency signal.

16. The system of claim 15, wherein the digital to radio frequency converter comprises a digital to analog converter.

17. The system of claim 7, wherein the digital host unit further comprises an alarm/control interface circuit coupled to the multiplexer.

18. The system of claim 1, wherein the at least two digital remote units each comprise:

an optical receiver;

a clock and bit recovery circuit coupled to an output of the optical receiver;

a demultiplexer coupled to an output of the clock and bit recovery circuit;

a digital to radio frequency converter coupled to the output of the demultiplexer;

a duplexer coupled to an output of the digital to radio frequency converter; and

a main radio frequency antenna coupled to an output of the duplexer.

19. The system of claim 1, wherein the at least two digital remote units each comprise:

a main radio frequency antenna;

a duplexer coupled to the main radio frequency antenna;

a radio frequency to digital converter coupled to an output of the duplexer;

a multiplexer coupled to an output of the radio frequency to digital converter; and

an optical transmitter coupled to an output of the multiplexer.

20. The system of claim 18, wherein the at least two digital remote units each further comprise:

a duplexer coupled to the main radio frequency antenna;

a radio frequency to digital converter coupled to an output of the duplexer;

a multiplexer coupled to an output of the radio frequency to digital converter; and

an optical transmitter coupled to an output of the multiplexer.

21. The system of claim 20, wherein the digital to radio frequency converter includes a digital to analog converter.

22. The system of claim 20, wherein the radio frequency converter includes an analog to digital converter.

23. The system of claim 20, wherein the at least two digital remote units each further comprise a programmable logic circuit coupled to an output of the radio frequency to digital converter and a reference oscillator coupled between the programmable logic

circuit and the clock and bit recovery circuit, wherein the programmable logic circuit monitors the system for error conditions and reports error modes.

24. The system of claim 23, wherein the at least two digital remote units each further comprise a synthesizer circuit coupled to an output of the programmable logic device and a first and a second local oscillator coupled to a first and a second output, respectively, of the synthesizer.

25. The system of claim 1, further comprising a digital expansion unit coupled to the digital host unit, wherein the digital expansion unit contains circuitry that performs bi-directional simultaneous digital radio frequency distribution between the digital host unit and the digital remote unit.

26. The system of claim 25, wherein the digital expansion unit comprises:

an optical receiver;

a clock and bit recovery circuit coupled to an output of the optical receiver; and

a plurality of optical transmitters coupled to an output of the clock and bit recovery circuit, wherein the optical transmitters are each coupleable to a digital remote unit or a digital expansion unit.

27. The system of claim 25, wherein the digital expansion unit comprises:

a plurality of optical receivers;

a plurality of clock and bit recovery circuits each coupled to an output of one of the plurality of optical receivers;

a plurality of demultiplexers each coupled to an output of one of the clock and bit recovery circuits;

a summer coupled to an output of each of the plurality of demultiplexers;

a multiplexer coupled to an output of the field programmable gate array; and

an optical transmitter coupled to an output of the multiplexer.

28. The system of claim 27, wherein the summer comprises a field programmable gate array that sums together digital radio frequency signals from the plurality of demultiplexers.

29. The system of claim 28, wherein the field programmable gate array includes an overflow algorithm circuit, which allows the summed digital radio frequency signals to saturate and keeps the summed signal within a defined number of bits.

30. The system of claim 29, wherein the overflow algorithm circuit comprises a limiter.

31. The system of claim 25, wherein the digital expansion unit is coupled to the digital host unit by a multimode fiber pair.

32. The system of claim 25, wherein the digital expansion unit is coupled to the digital host unit by single mode fiber.

33. A digital radio frequency transport system, comprising:

a digital host unit;

at least one digital expansion unit coupled to the digital host unit; and

at least two digital remote units, each coupled to one of the digital host unit and the digital expansion unit, wherein the digital host unit includes shared circuitry that performs bi-directional simultaneous digital radio frequency distribution between the digital host unit and the at least two digital remote units.

34. The system of claim 33, further comprising a wireless interface device coupled to the digital host unit.

35. The system of claim 34, wherein the wireless interface device comprises a base station that couples directly to the digital host unit via coaxial cables.

36. The system of claim 34, wherein the wireless interface device comprises a base station that wirelessly connects to the digital host unit via a bi-directional amplifier that is coupled to an antenna.

37. The system of claim 33, wherein at least one digital remote unit is to coupled the digital host unit.

38. The system of claim 33, wherein at least one digital remote unit is coupled to one of the at least two digital expansion units.

39. The system of claim 33, wherein the at least one digital expansion units are each coupled to the digital host unit via a multimode fiber pair.

40. The system of claim 33, wherein the at least one digital expansion unit is coupled to the digital host unit via a single mode fiber.

41. The system of claim 33, wherein the at least one digital expansion unit comprises:

an optical receiver;

a clock and bit recovery circuit coupled to an output of the optical receiver; and

a plurality of optical transmitters coupled to an output of the clock and bit recovery circuit, wherein the optical transmitters are each coupleable to a digital remote unit or a digital expansion unit.

42. The system of claim 33, wherein the at least one digital expansion unit comprises:

a plurality of optical receivers;

a plurality of clock and bit recovery circuits each coupled to an output of one of the plurality of optical receivers;

a plurality of demultiplexers each coupled to an output of one of the clock and bit recovery circuits;

a summer coupled to an output of each of the plurality of demultiplexers;

a multiplexer coupled to an output of the field programmable gate array; and

an optical transmitter coupled to an output of the multiplexer.

43. The system of claim 42, wherein the summer includes a field programmable gate array that sums together digital radio frequency signals from the plurality of demultiplexers.

44. The system of claim 42, wherein the field programmable gate array includes an overflow algorithm circuit, which allows the summed digital radio frequency signals to saturate and keeps the summed signal within a defined number of bits.

45. The system of claim 44, wherein the overflow algorithm circuit comprises a limiter.

46. The system of claim 33, wherein the digital host unit includes a radio frequency to digital converter that converts a main radio frequency signal to a digitized radio frequency signal.

47. The system of claim 46, wherein the digital host unit further includes a multiplexer which splits the digitized radio frequency signal into at least two digital signals for optical transmission to the at least two digital remote units.

48. The system of claim 33, wherein the digital host unit includes local oscillators coupled to a reference oscillator for synchronization of the radio frequency signal in the forward direction and in the reverse direction.

49. The system of claim 33, wherein the digital host unit includes:

at least two optical receivers each coupled to one of the at least two digital expansion units;

at least two clock and bit recover circuits each coupled to an output of one of the at least two optical receivers; and

1at least two demultiplexers each coupled to an output of one of the at least two clock and bit recovery circuits.

50. The system of claim 49, wherein the digital host unit further includes a summer coupled to an output of each of the at least two demultiplexers, wherein the summer receives a digital radio frequency signal from each of the at least two demultiplexers.

51. The system of claim 50, wherein the summer includes a field programmable gate array that sums together the digital radio frequency signals from each of the at least two demultiplexers.

52. The system of claim 51, wherein the field programmable gate array includes an overflow algorithm circuit, which allows the summed digital radio frequency signals to saturate and keeps the summed signal within a defined number of bits.

53. The system of claim 52, wherein the overflow algorithm circuit comprises a limiter.

54. The system of claim 52, wherein the digital host unit further includes a digital to radio frequency converter coupled to an output of the field programmable gate array, wherein the radio frequency converter receives the summed digital radio frequency signal and converts it to an analog radio frequency signal.

55. The system of claim 54, wherein the digital to radio frequency converter comprises a digital to analog converter.

56. The system of claim 51, wherein the field programmable gate array includes an alarm/control interface circuit.

57. A method of performing multipoint-to-point digital radio frequency transport, the method comprising:

receiving analog radio frequency signals at multiple digital remote units;

converting the analog radio frequency signals to digital radio frequency signals at each of the digital remote units;

optically transmitting the digital radio frequency signals from each of the digital remote units to a digital host unit;

receiving the multiple digital radio frequency signals at the digital host unit;

summing the multiple digital radio frequency signals together; and

converting the digital radio frequency signals back to analog radio frequency signals and transmitting the signals to a wireless interface device for further transmission to a switched telephone network.

58. The method of claim 57, wherein converting the analog radio frequency signals to digital radio frequency signals comprises amplifying the analog radio frequency signals.

59. The method of claim 57, wherein converting the analog radio frequency signals to digital radio frequency signals comprises synchronizing a reverse path local oscillator to a mater clock so as to reduce end-to-end frequency translation.

60. A method of performing point-to-multipoint digital radio frequency transport, the method comprising:

receiving radio frequency signals at a digital host unit;

converting the radio frequency signals to a digitized radio frequency spectrum;

optically transmitting the digitized radio frequency spectrum to a plurality of digital remote units;

receiving the digitized radio frequency spectrum at the plurality of digital remote units;

converting the digitized radio frequency spectrum to analog radio frequency signals; and

transmitting the analog radio frequency signals via a main radio frequency antenna at each of the plurality of digital remote units.

61. The method of claim 60, wherein converting the radio frequency signals to a digitized radio frequency spectrum comprises amplifying the radio frequency signals.

62. The method of claim 60, wherein converting the radio frequency signals to a digitized radio frequency spectrum digital radio frequency signals comprises synchronizing a forward path local oscillator to a reference oscillator so as to reduce end-to-end frequency translation.

63. The method of claim 60, wherein converting the digitized radio frequency spectrum to analog radio frequency signals comprises amplifying the analog radio frequency signals.

64. The method of claim 60, wherein converting the digitized radio frequency spectrum to analog radio frequency signals comprises synchronizing a forward path local oscillator to a reference oscillator so as to reduce end-to-end frequency translation.

65 . A method of performing point-to-multipoint digital radio frequency transport, the method comprising:

receiving radio frequency signals at a digital host unit;

converting the radio frequency signals to a digitized radio frequency spectrum;

optically transmitting a first digitized radio frequency spectrum to a first plurality of digital remote units and at least one digital expansion unit;

receiving the digitized radio frequency spectrum at the first plurality of digital remote units;

converting the digitized radio frequency spectrum to analog radio frequency signals at each of the first plurality of digital remote units;

receiving the digital radio frequency signals at the at least one digital expansion unit;

optically transmitting a second digitized radio frequency spectrum to a second plurality of digital remote units;

receiving the second digitized radio frequency spectrum at the second plurality of digital remote units;

converting the second digitized radio frequency spectrum to analog radio frequency signals at each of the second plurality of digital remote units; and

transmitting the analog radio frequency signals via a main radio frequency antenna at each of the first and second plurality of digital remote units.

66. A digital radio frequency transport system, comprising:

a digital host unit; and

at least two digital remote units coupled to the digital host unit, wherein the at least two digital remote units each include:

a main radio frequency antenna;

a duplexer coupled to the main radio frequency antenna which receives radio frequency signals in the reverse path and transmits radio frequency signals in the forward path;

a radio frequency to digital converter coupled to the duplexer in the reverse path;

a digital to radio frequency converter coupled to the duplexer in the forward path;

a multiplexer chip set coupled to the radio frequency to digital converter in the reverse path and the digital to radio frequency converter in the forward path;

an optical transmitter coupled to an output of the multiplexer chip set; and

an optical receiver coupled to an input of the multiplexer chip set;

wherein the digital host unit includes shared circuitry that performs bi-directional simultaneous digital radio frequency distribution between the digital host unit and the at least two digital remote units.

67. The system of claim 66, wherein the digital host unit includes an alarm/control interface circuit.

68. The system of claim 66, wherein the digital host unit includes:

at least two optical receivers each coupled to one of the at least two digital remote units;

at least two clock and bit recover circuits each coupled to an output of one of the at least two optical receivers; and

at least two demultiplexers each coupled to an output of one of the at least two clock and bit recovery circuits.

69. The system of claim 66, wherein the digital host unit further includes a field programmable gate array coupled to an output of each of the at least two demultiplexers, wherein the field programmable gate array receives a digital radio frequency signal from each of the at least two demultiplexers.

70. The system of claim 69, wherein the field programmable gate array includes a summer that sums together the digital radio frequency signals from each of the at least two demultiplexers.

71. The system of claim 70, wherein the field programmable gate array further includes an overflow algorithm circuit, which allows the summed digital radio frequency signals to saturate and keeps the summed signal within a defined number of bits.

72. The system of claim 71, wherein the overflow algorithm circuit comprises a limiter.

73. The system of claim 70, wherein the digital host unit further includes a digital to radio frequency converter coupled to an output of the field programmable gate array, wherein the radio frequency converter receives the summed digital radio frequency signal and converts it to an analog radio frequency signal.

74. The system of claim 73, wherein the digital to radio frequency converter comprises a digital to analog converter.

75. A digital radio frequency transport system, comprising:

a digital host unit, wherein the digital host unit includes:

a radio frequency to digital converter;

a multiplexer coupled to an output of the radio frequency to digital converter;

a plurality of optical transmitters coupled to an output of the multiplexer

a first local oscillator coupled to an input of the radio frequency to digital converter;

a reference oscillator coupled to an input of the first local oscillator;

a second local oscillator coupled to an output of the reference oscillator;

a digital to radio frequency converter coupled to an output of the second local oscillator;

a channel summer coupled to an input of the digital to radio frequency converter;

a plurality of demultiplexers coupled to the channel summer;

a plurality of clock and bit recovery circuits, wherein each of the plurality of clock and bit recovery circuits are coupled to one of each of the plurality of demultiplexers; and

a plurality of optical receivers, wherein each of the plurality of optical receivers are coupled to one of each of the plurality of optical receivers;

at least two digital remote units each coupled to one of the plurality of optical receivers, wherein the digital host unit includes shared circuitry that performs bi-directional simultaneous digital radio frequency distribution between the digital host unit and the at least two digital remote units.

76. The system of claim 75, wherein the at least two digital remote units each comprise:

an optical receiver;

a clock and bit recovery circuit coupled to an output of the optical receiver;

a demultiplexer coupled to an output of the clock and bit recovery circuit;

a digital to radio frequency converter coupled to an output of the demultiplexer;

a duplexer coupled to an output of the digital to radio frequency converter; and

a main radio frequency antenna coupled to an output of the duplexer.

77. The system of claim 75, wherein the at least two digital remote units each comprise:

a main radio frequency antenna;

a duplexer coupled to the main radio frequency antenna;

a radio frequency to digital converter coupled to an output of the duplexer;

a multiplexer coupled to an output of the radio frequency to digital converter; and

an optical transmitter coupled to an output of the multiplexer.

78. The system of claim 76, wherein the at least two digital remote units each further comprise:

a duplexer coupled to the main radio frequency antenna;

a radio frequency to digital converter coupled to an output of the duplexer;

a multiplexer coupled to an output of the radio frequency to digital converter; and

an optical transmitter coupled to an output of the multiplexer.

79. The system of claim 78, wherein the digital to radio frequency converter includes a digital to analog converter.

80. The system of claim 78, wherein the radio frequency converter includes an analog to digital converter.

81. The system of claim 78, wherein the at least two digital remote units each further comprise a programmable logic circuit coupled to an output of the radio frequency to digital converter and a reference oscillator coupled between the programmable logic circuit and the clock and bit recovery circuit, wherein the programmable logic circuit monitors the system for error conditions and reports error modes.

82. The system of claim 81, wherein the at least two digital remote units each further comprise a synthesizer circuit coupled to an output of the programmable logic device and a first and a second local oscillator coupled to a first and a second output, respectively, of the synthesizer.

83. A digital radio frequency transport system, comprising:

a digital host unit, wherein the digital host unit includes a channel summer;

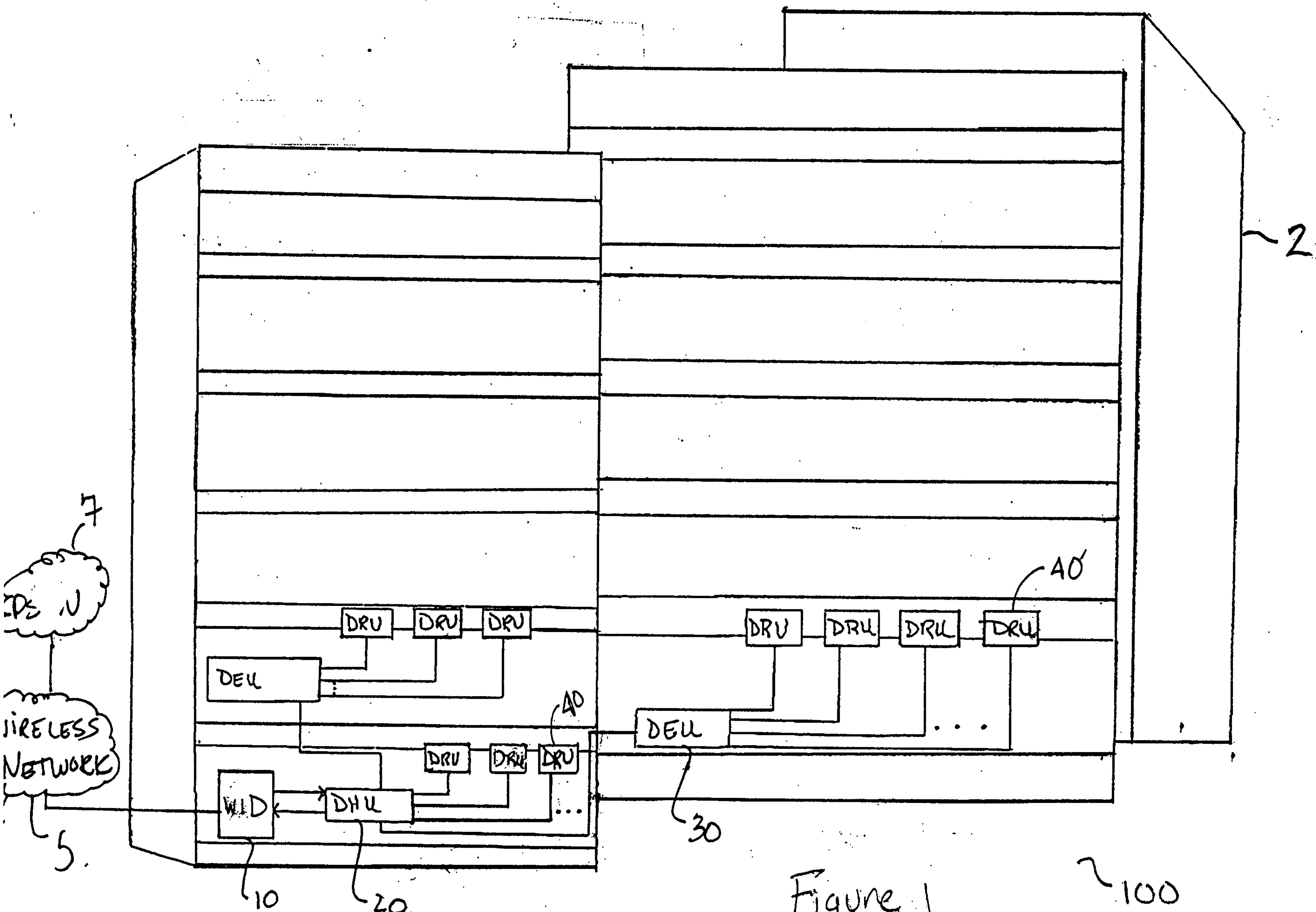
at least one digital expansion unit coupled to the digital host unit; and

at least two digital remote units coupled to the digital host unit, wherein the digital host unit includes shared circuitry that performs bi-directional simultaneous

digital radio frequency distribution between the digital host unit and the at least two digital remote units.

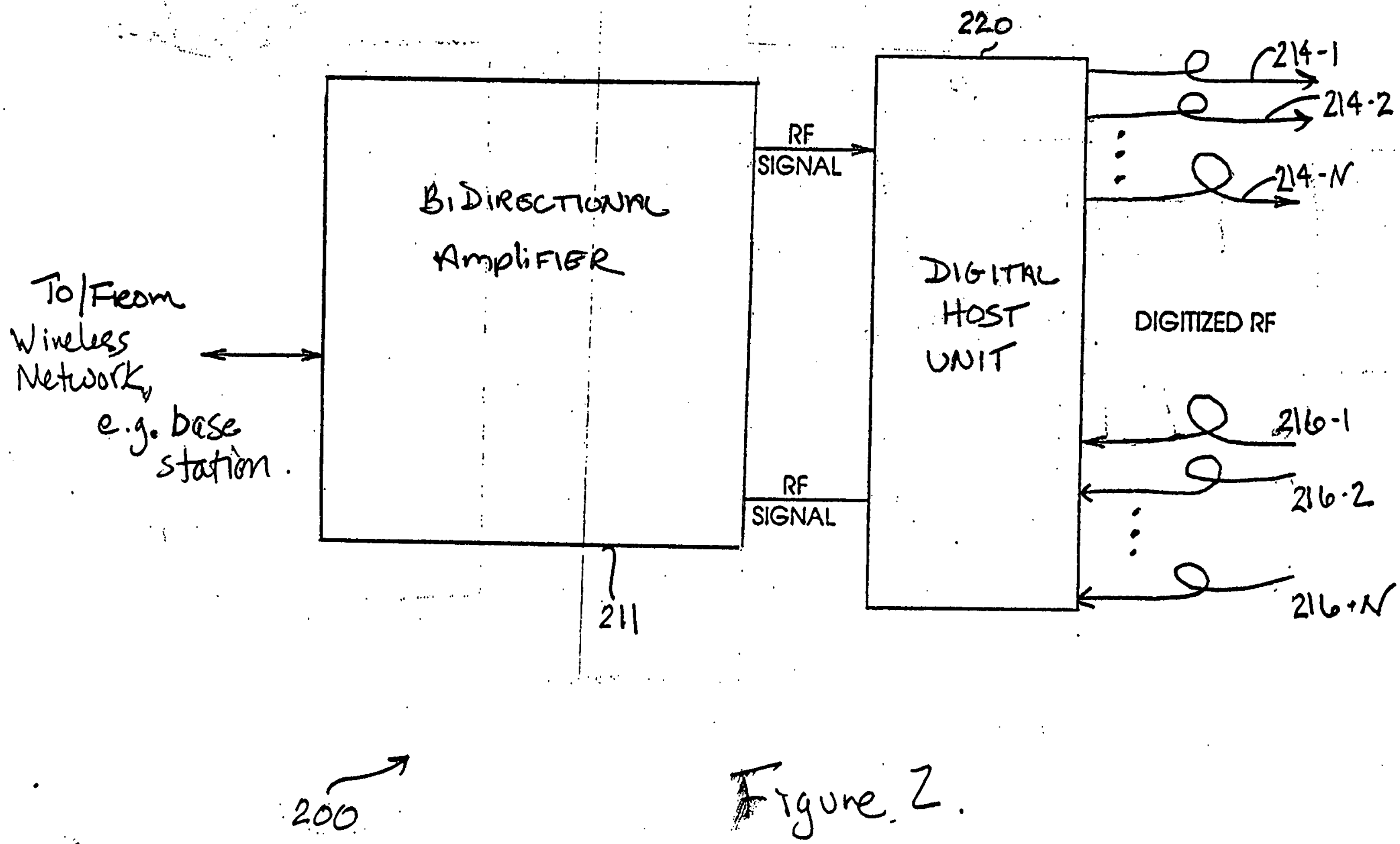
Abstract of the Disclosure

A digital radio frequency transport system that performs bi-directional simultaneous digital radio frequency distribution is provided. The transport system includes a digital host unit and at least two digital remote units coupled to the digital host unit. The bi-directional simultaneous digital radio frequency distribution is performed between the digital host unit and the at least two digital remote units.



WIRELESS NETWORK
7
5
DEU
DRU
DRU
DRU
WID
DHU
DRU
DRU
DRU
40
DEU
DRU
DRU
DRU
DRU
40'
30
10
20
2
100

Figure 1



To/From Wireless Network, e.g. base station.
BiDirectional Amplifier
211
RF SIGNAL
RF SIGNAL
220
Digital Host Unit
214-1
214-2
214-N
DIGITIZED RF
216-1
216-2
216-N
200

Figure 2.

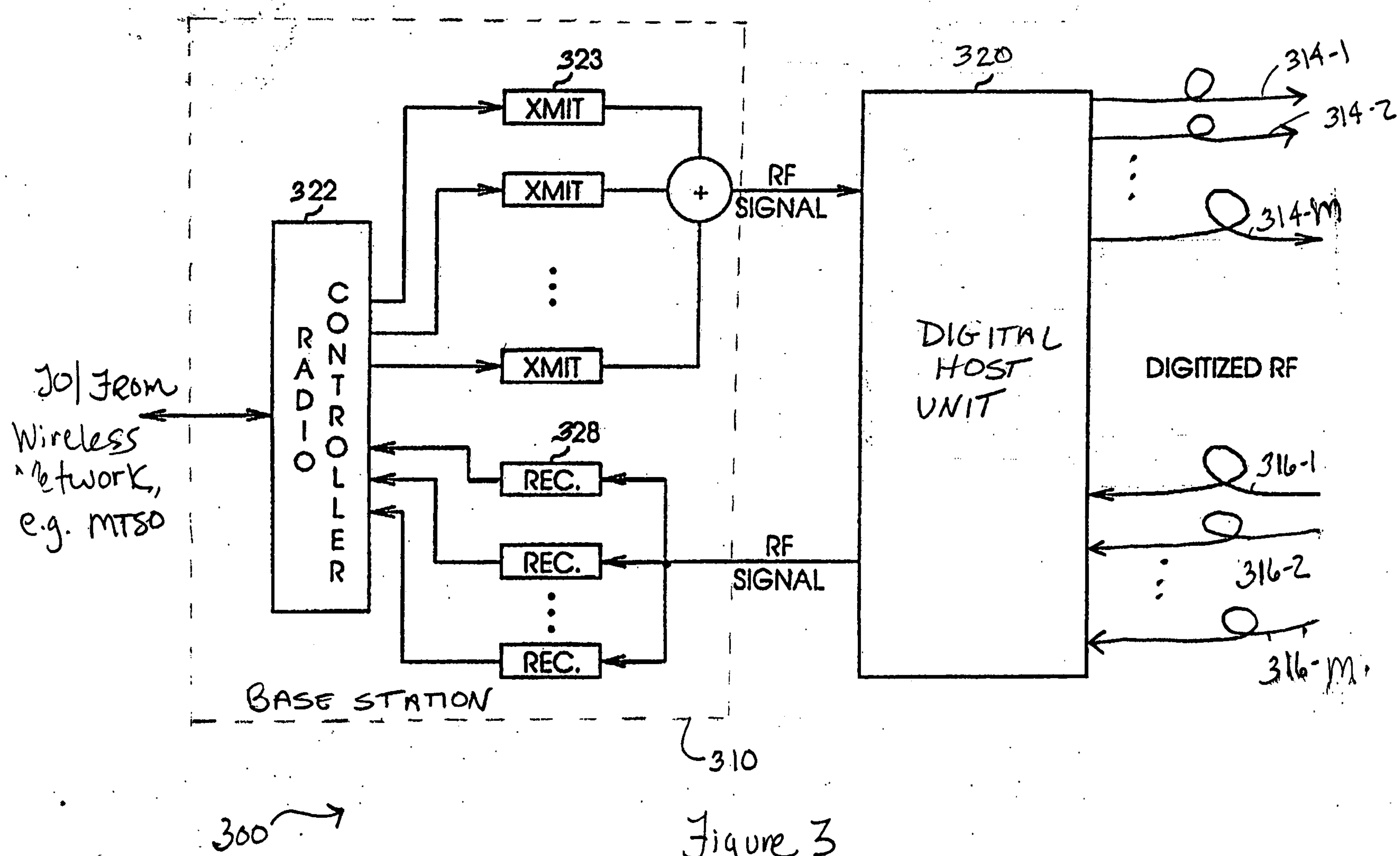
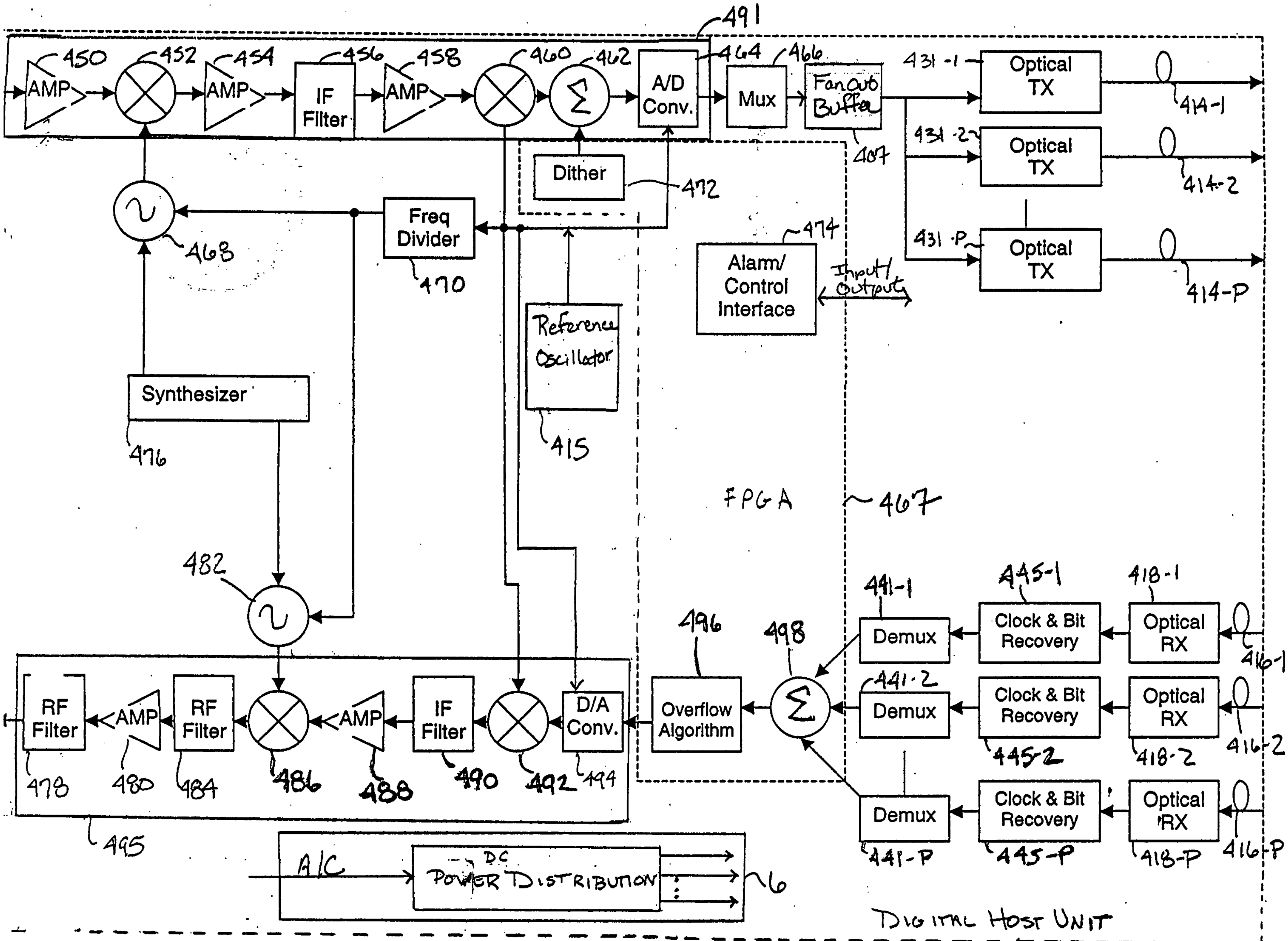

To/From
Wireless
Network,
e.g. MTSO
322
RADIO CONTROLLER
323
XMIT
XMIT
XMIT
328
REC.
REC.
REC.
RF
SIGNAL
RF
SIGNAL
BASE STATION
310
320
DIGITAL
HOST
UNIT
DIGITIZED RF
314-1
314-2
314-M
316-1
316-2
316-M
300

Figure 3



491
450
AMP
452
454
AMP
456
IF Filter
458
AMP
460
462
A/D Conv.
464
466
Mux
Fan Out Buffer
407
431-1
431-2
431-P
Optical TX
Optical TX
Optical TX
414-1
414-2
414-P
Dither
472
468
Freq Divider
470
474
Alarm/ Control Interface
Input/ Output
Reference Oscillator
415
Synthesizer
476
FPGA
467
482
441-1
445-1
418-1
Demux
Clock & Bit Recovery
Optical RX
416-1
496
498
441-2
Demux
Clock & Bit Recovery
Optical RX
445-2
418-2
416-2
RF Filter
AMP
RF Filter
AMP
IF Filter
D/A Conv.
Overflow Algorithm
478
480
484
486
488
490
492
494
Demux
Clock & Bit Recovery
Optical RX
441-P
445-P
418-P
416-P
495
A/C
DC
Power Distribution
6
Digital Host Unit
420

Figure 4

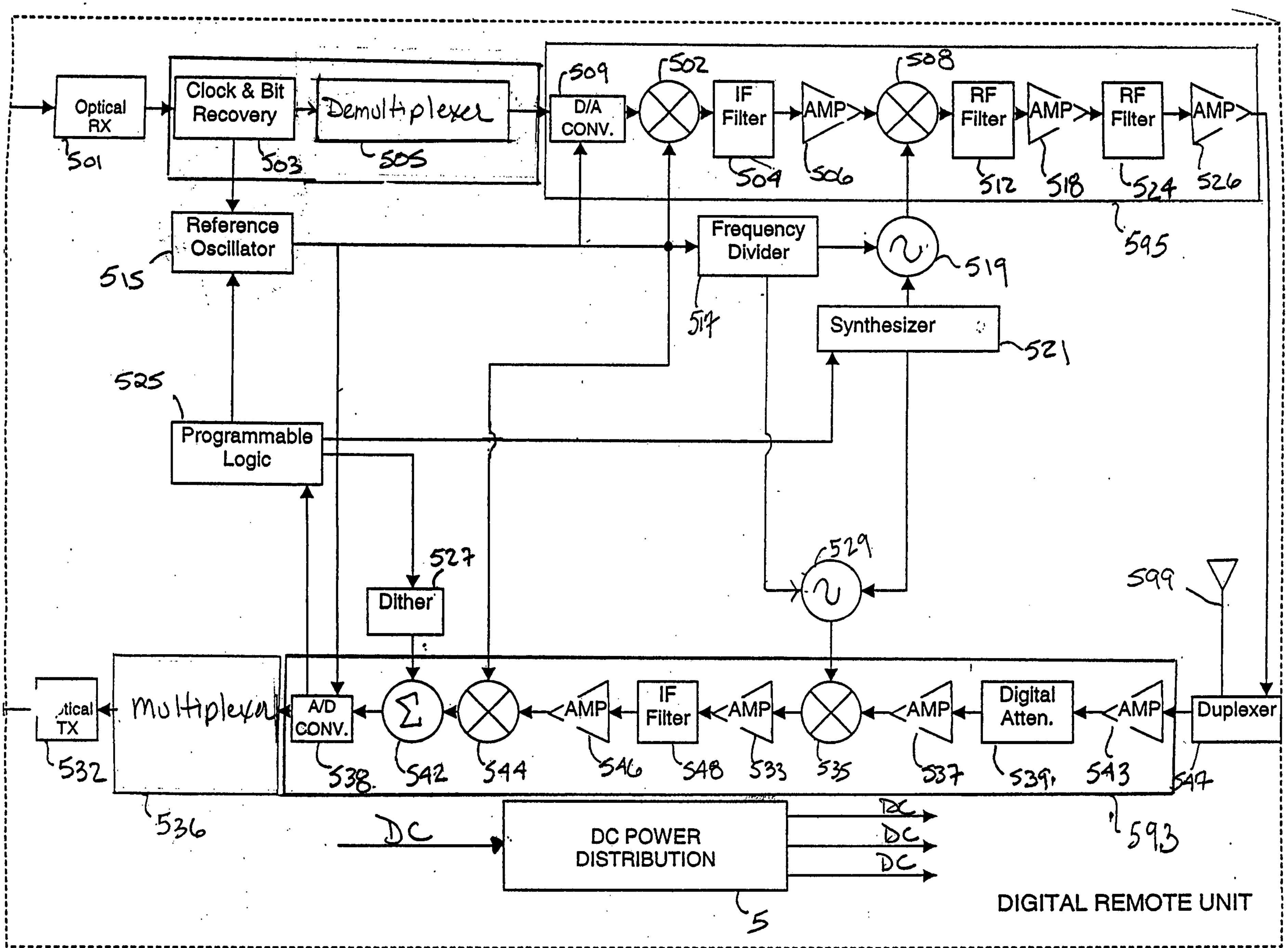

Optical RX
Clock & Bit Recovery
Demultiplexer
D/A CONV.
IF Filter
AMP
RF Filter
Reference Oscillator
Frequency Divider
Synthesizer
Programmable Logic
Dither
Duplexer
Digital Atten.
A/D CONV.
Multiplexer
Optical TX
DC POWER DISTRIBUTION
DC
DIGITAL REMOTE UNIT
501
503
505
509
502
504
506
508
512
518
524
526
595
515
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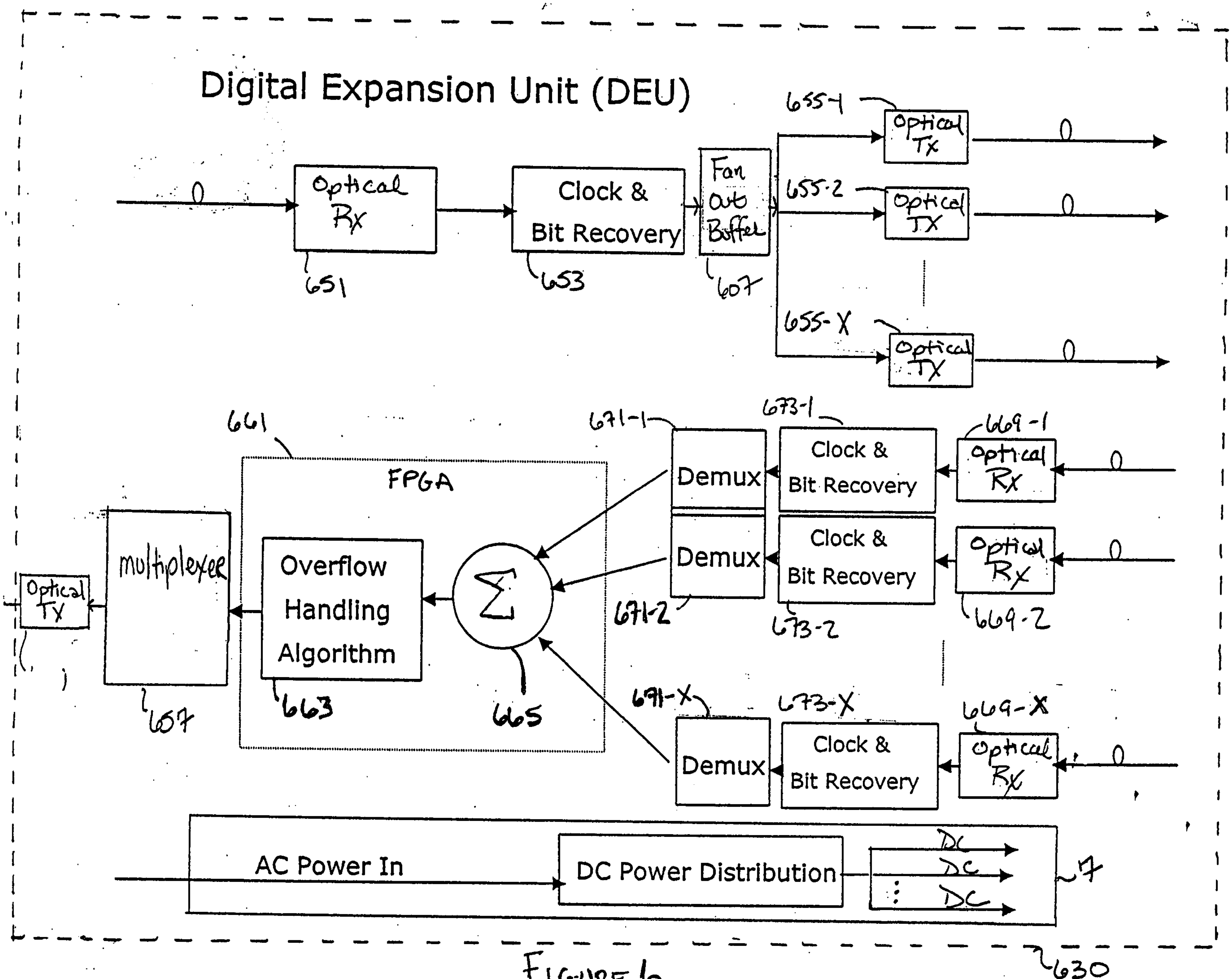
FIGURE 5



Digital Expansion Unit (DEU)
Optical Rx
651
Clock & Bit Recovery
653
Fan Out Buffer
607
655-1
Optical Tx
655-2
Optical TX
655-X
Optical TX
661
FPGA
Overflow Handling Algorithm
663
Σ
665
multiplexer
657
Optical Tx
671-1
Demux
671-2
Demux
671-X
Demux
673-1
Clock & Bit Recovery
673-2
Clock & Bit Recovery
673-X
Clock & Bit Recovery
669-1
Optical Rx
669-2
Optical Rx
669-X
Optical Rx
AC Power In
DC Power Distribution
DC
DC
DC
7
630

FIGURE 6

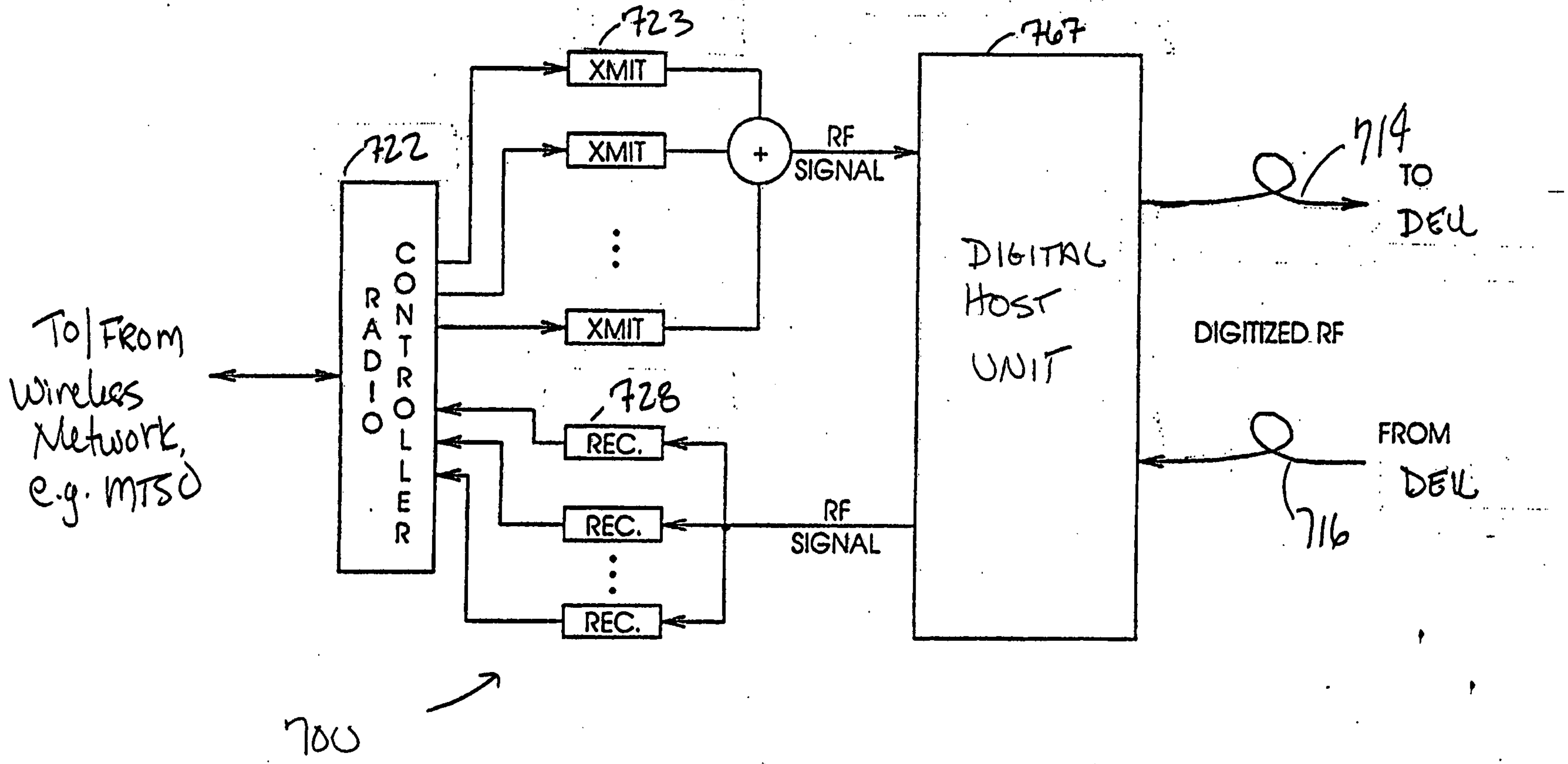

To/FROM Wireless Network, e.g. MTSO
RADIO CONTROLLER
722
XMIT
XMIT
XMIT
723
REC.
REC.
REC.
728
RF SIGNAL
RF SIGNAL
DIGITAL HOST UNIT
767
DIGITIZED RF
714
TO DEU
FROM DEU
716
700

Figure 7

Channel Summer

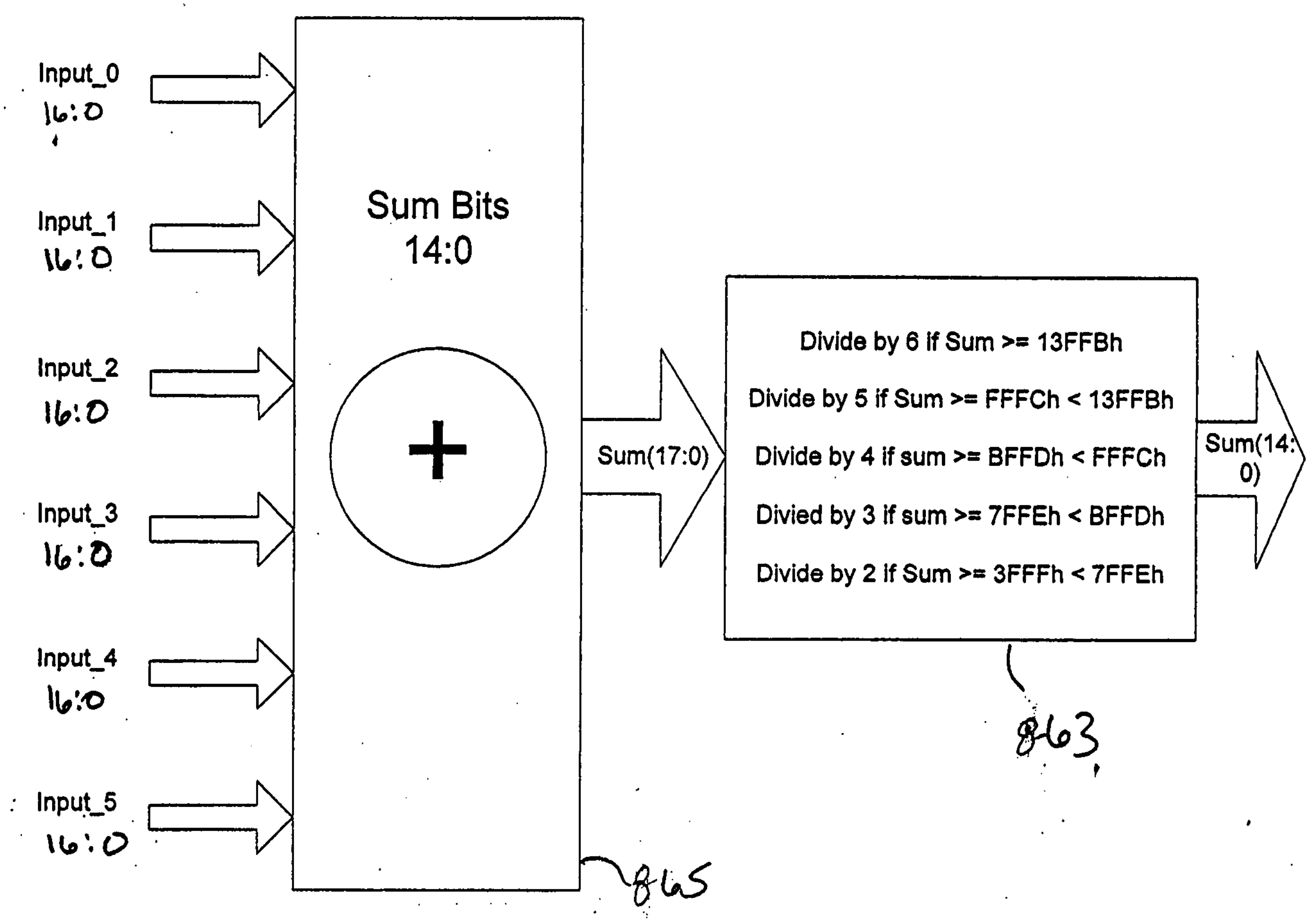


Figure 87